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FEBRUARY 1997

CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT
CONCEPTUAL DESIGN AND DRAFT EIS/EIR

Evaluation of CalTrain Locomotive Propulsion Options

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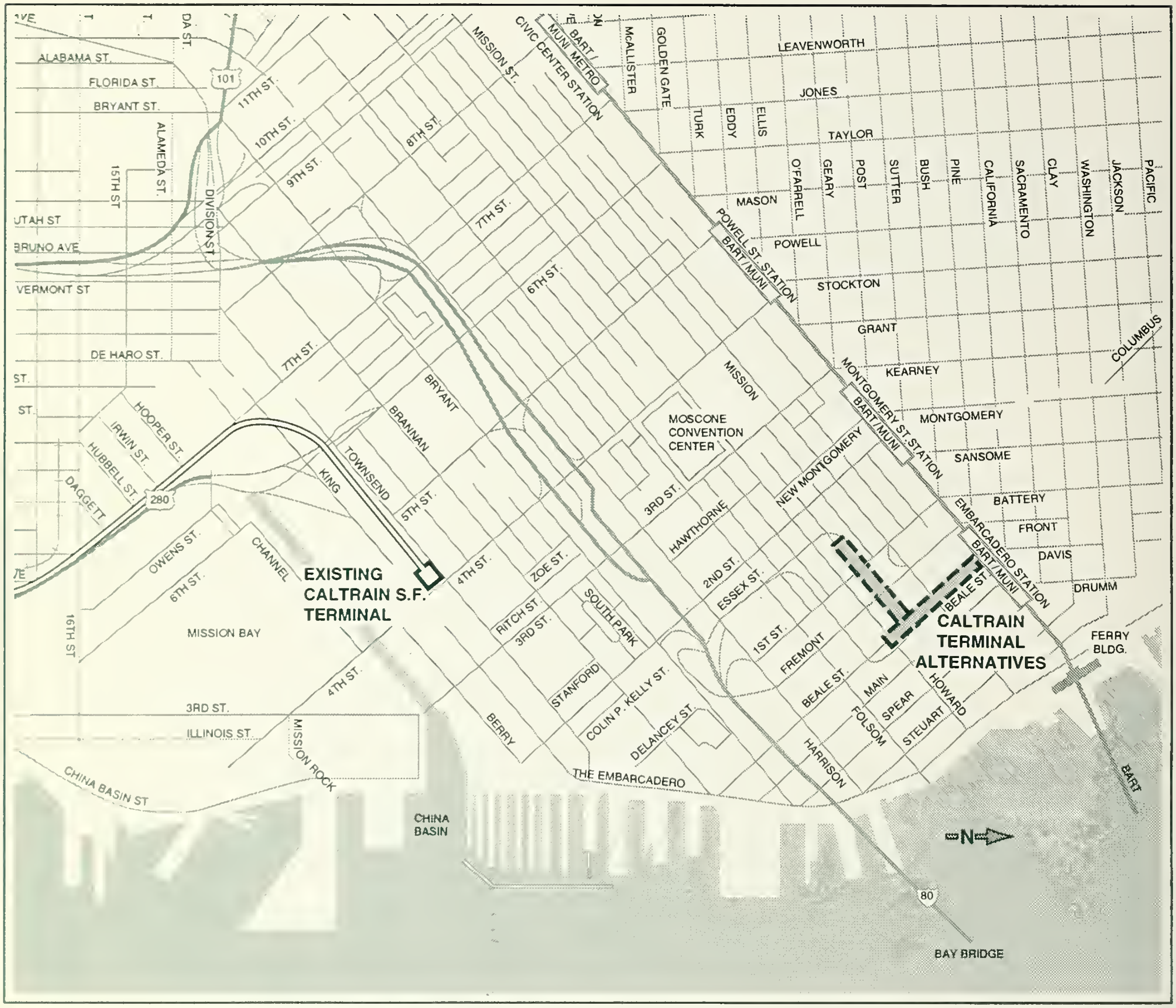
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CALTRAIN TERMINAL ALTERNATIVES
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MUNI METRO
CIVIC CENTER STATION
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BART/MUNI
MONTGOMERY ST. STATION
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CHINA BASIN
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CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT

EVALUATION OF CALTRAIN LOCOMOTIVE PROPULSION OPTIONS

Issued
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CALTRAIN SAN FRANCISCO DOWNTOWN EXTENSION PROJECT
EVALUATION OF CALTRAIN LOCOMOTIVE PROPULSION OPTIONS

1.0 INTRODUCTION

1.1 DOWNTOWN EXTENSION PROJECT

The CalTrain San Francisco Downtown Extension (DTX) would extend CalTrain service from the existing San Francisco terminal at Fourth and Townsend Streets to an underground station at the site of the Transbay Terminal. The alignment adopted by the Joint Powers Board (JPB) would follow the existing CalTrain right-of-way immediately east of Seventh Street and continue on the surface along Townsend Street to Fourth Street. From Fourth and Townsend, a subway would be built through South Beach under Rincon Hill. North of Folsom Street, the subway alignment would follow the right-of-way of the Transbay Terminal outbound bus ramp to the underground station. The total length of the subway and terminal station would be about 1.3 miles.

As a consequence of constructing an underground station at the Transbay Terminal site, the existing bus terminal would be razed and either relocated one block to the east between Main and Beale or rebuilt above the CalTrain station. A CalTrain train storage yard would be constructed in the Mission Bay area. This technical report addresses the issues and trade-offs for the propulsion options being considered.

1.2 LOCOMOTIVE PROPULSION OPTIONS CONSIDERED

Initially, a wide range of Caltrain locomotive propulsion options were considered for the DTX Project, all grouped within three main categories: fossil fuel, dual mode (fossil fuel on the surface and electric in the subway) and full system electrification. The options considered were:

- Existing conventional, state-of-the-art diesel locomotives;
- "Clean" Diesel -- existing diesel locomotives retrofitted with low-emission technology;
- Liquefied Natural Gas (LNG) locomotives;
- Adding/Removing an electric locomotive near the subway entrance;
- Dual-mode (diesel on surface and electric in subway) locomotives using 1500V DC power supply;
- Dual mode (diesel on surface and electric in subway) power pack units using 25,000 Volt (25kV) AC power supply; and
- Straight electric with full system electrification (25kV AC power supply).

As part of the Design Options Screening (DOS) process for the DTX study, the three fossil fuel-powered locomotive options were seriously considered and rejected as technically infeasible. The other options were evaluated in more detail following the DOS process. As part of this evaluation, the option of adding or removing electric locomotives at the subway entrance to shunt the trains in and out of the subway was

rejected. This report outlines the reasons for rejecting options, describes the three remaining options in detail and presents recommendations for the JPB to consider.

1.3 LOCOMOTIVE PROPULSION OPTIONS REJECTED

Current State-of-the-Art Diesel Locomotives

CalTrain currently operates a fleet of 20 F-40 PH diesel locomotives. Operating the existing diesel locomotives in the subway and underground station would produce diesel air pollutants that exceed health standards for clean air. Reducing emissions to an acceptable level would not be technically feasible. For these reasons, this propulsion option was dropped.

"Clean" Diesel Locomotives

"Clean" diesel refers to a retrofitted diesel engine that incorporates new technology to reduce diesel air pollutants. The retrofit engine, in combination with an extensive ventilation system, could permit diesel locomotives to operate in a subway and underground passenger station environment without exceeding health standards for clean air. "Clean" diesel, along with LNG, were felt to represent the least-cost locomotive propulsion/ventilation system options for the CalTrain San Francisco Downtown Extension.

In spite of the reduction in pollutant emissions, "clean" diesel locomotives still discharge a high level of nitrogen oxides, as well as carbon monoxide, formaldehyde, and particulate matter. The ventilation system needed to remove these pollutants in the subway would require 200-square-foot ventilation ducts on average every 200 feet along the alignment. In congested areas surrounding the underground terminal stations, large and tall ventilation stacks would need to be attached to adjacent buildings to ensure that the diesel locomotive pollutants are released well-above street level. Even with this extensive ventilation system, it is likely that passengers would still smell diesel fumes in the station and subway tunnel.

The level of pollutant emissions in the subway and underground station combined with the height and close spacing of ventilation stacks or chimneys led the JPB to eliminate "clean" diesel from further study. For more information on clean-diesel technology, see Appendix D.

Liquefied Natural Gas Locomotives

LNG propulsion, which has recently been employed on freight locomotives in surface operations, could reduce the level of nitrogen oxides by two-thirds over diesel propulsion. LNG would be stored in heavily-insulated tanks on-board retrofitted diesel locomotives. All existing CalTrain diesel locomotives would be converted to LNG and corresponding LNG fueling facilities would be installed. The cost of conversion would be about the same as for "clean" diesel locomotives, but would be substantially below the cost of full

Caltrain system electrification. For the CalTrain system, one tank of LNG could be expected to power a locomotive for only one day's trips (about 240 miles).

LNG has a greater safety risk than diesel or electric propulsion. The gas is stored at around minus 200 degrees Fahrenheit. If released unexpectedly in an underground area, it would quickly vaporize and, without proper dispersal, collect on the ceiling of the enclosed area. Proper ventilation and a natural gas detector system located along the ceiling of the underground station area and subway would be necessary to minimize the possibility of vaporized LNG exploding. Approximately twenty-two 200-square-foot ventilation ducts, spaced about 800 feet apart along the subway alignment, would be required.

Because of the serious fire and life/safety issues associated with LNG use, the San Francisco Fire Department recommended against permitting use of LNG locomotives in the tunnel; therefore, this propulsion option was dropped from further consideration. For more information on LNG technology, see Appendix D.

Adding/Removing Electric Locomotives Near the Subway Entrance

The option of adding and removing electric locomotives near the subway entrance, so that trains would operate using electric propulsion in the subway and with the existing diesel locomotives on the surface, was considered as a way to reduce the project's cost. This option was rejected because it could take from 15 to 30 minutes to switch locomotives and perform the necessary brake line safety tests. The additional time would negate any potential time improvement over existing conditions for the DTX project.

1.4 LOCOMOTIVE PROPULSION OPTIONS CARRIED FORWARD FOR FURTHER EVALUATION

Use of electric-powered locomotives in the DTX subway would obviate the emission and life/safety concerns associated with diesel and LNG propulsion. Three technologies employing electric locomotives for subway operation are being considered. They are:

- Diesel locomotives coupled with electric power pack units;
- 1500V DC dual mode locomotives; and
- Straight electric locomotives with full electrification (25kV AC).

These options are discussed in Sections 2, 3, and 4 below.

2.0 DUAL MODE: CONVENTIONAL DIESEL LOCOMOTIVES COUPLED WITH ELECTRIC POWER PACK UNITS

2.1 MOTIVE POWER CHARACTERISTICS

Conventional diesel locomotives operate by generating electric power from a diesel engine coupled to an electric generator and feeding it to electric motors located on the axles that drive the locomotive wheels. The electric power pack unit concept is to provide electric power to a diesel locomotive through a "power-pack". The power pack could be built into the locomotive or be provided on a separate car attached to the locomotive. The main advantage of the power pack unit is that it could be built to operate on 25,000 Volt AC power, CalTrain's preferred long-range electrification voltage.

The power pack unit would carry the necessary equipment to allow the locomotive to propel and control the train using electric power while the diesel engine is shut down. The unit would contain the power conditioning equipment (the basic on-board power source in the electric mode), transformers, rectifiers, air compressors, and head-end power for the passenger cars, as well as the pantograph for electric collection from the overhead wire (catenary).

The weight of the power unit would be approximately 90 tons. The power unit would require a main transformer, creating additional weight. The additional weight would constrain the ability of the existing CalTrain F-40 or equivalent diesel locomotive to power a 10-car train, CalTrain's design requirement. For a seven-car train, the maximum speed on level track with fully loaded cars is expected to be less than 70 miles per hour. Operating diesel locomotives with AC tractive capabilities instead of the DC tractive capabilities used by the existing F-40 locomotives would improve the locomotives' performance somewhat in the subway and on level track.[1]

More information about the weight and tractive effort of diesel locomotives carrying a power pack unit is indicated in the letter from Paul G. Eiben, Director of Engineering, Kaiser-EDA, Incorporated and presented in Appendix C.

The existing (or new replacement) F-40 diesel locomotives would not have sufficient space to house the power pack unit without increasing the length of the locomotive. The electric power pack would add 65 to 89 feet per train, increasing the length of the track needed between the end of the station platforms and the clear point for the track at the interlocking signal. Station platform lengths would be unaffected by the increased train length. The additional length would also constrain the locomotive's ability to negotiate sharp 16-degree curves required for the DTX alignment. Because of these constraints,

---

[1] Tractive capabilities derive from the conversion of diesel power to electric power to propel diesel locomotives. The diesel power operates a generator, installed within diesel locomotives, to drive an electric motor, which can operate on either AC or DC power. AC-derived tractive effects produce greater acceleration and hauling capabilities.

the new diesels would be modified to operate in tandem with a separate power pack unit carrying the electric power mode apparatus.

For the power pack propulsion option, the conversion to power pack units would occur at the end of the F-40's life cycle, around 2005 to 2010. Modifications to off-the-shelf diesel locomotives would include: 1) Multiple Unit (MU) control functions for dual mode operation; 2) a battery charging system for use in electric mode; 3) head-end power circuits to accept power from either the locomotive or the electric power pack; and 4) remote diesel engine start, automatic logic sequence, and interlocks. Control functions such as pantograph control and shutting down/starting up the diesel engine would be trainlined to allow operation from either end of the train (the locomotive cab or the control cab) in diesel or electric mode.

During electric mode operation, the diesel locomotive would not supply power or compressed air, since the locomotive's traction alternator and air compressor are directly driven by the diesel engine. Consequently, the electric power pack would need its own head-end power supply and main reservoir air source in addition to a traction power collection and conversion function and traction motors. Dynamic braking might also be included due to the three percent grade of the proposed subway and the added weight of the power pack. The electric power pack would, in effect, become an electric locomotive without operator controls.

If the electric power pack concept were to be implemented, the following issues would need evaluation:

- Potential safety problems associated with high voltage, high amperage currents passing between the power pack unit and the locomotive;
- Fire and life/safety issues in the event of a train derailment in which the locomotive's diesel fuel tanks ruptured;
- Use of the electric power pack as the control cab car; and
- Use of a modified, used electric locomotive for the electric power pack.

More information regarding the characteristics of the electric power pack is contained in the letter from Maurice M. Rix, Senior Engineer, LTK Engineering Services presented in Appendix C.

2.2 ELECTRICAL SYSTEM REQUIREMENTS

The electric power pack could operate either with AC or DC electrification systems. However, there are no significant advantages of a 1500 V DC power pack option over a dual mode locomotive option. One key reason is that CalTrain's goal is electrification using a 25kV AC system. Dual mode operation with an electric power pack could be an interim step towards the 25kV AC system, and its electrical system requirements could be designed to conform with this long-term goal.

Safety concerns related to at-grade operation along Townsend Street and the low 10" high platforms in the terminal station preclude the use of a third rail to provide electric

power to the locomotive. Instead, catenary (overhead wire) would distribute electricity to the electric power pack. The catenary would be extended approximately two miles beyond the subway portal, since the diesel engines require approximately two to three minutes of time for starting and warm-up before they are able to provide propulsion power during the electric-to-diesel transition.

As stated previously, high voltage AC current would require a main transformer in the power pack to step down the power supply from 25 kV to the lower voltage utilized by the electric motors (600 volts). For the 25kV AC power supply, only one substation would be needed.

2.3 COST AND IMPLEMENTATION SCHEDULE

Capital Cost

The unit cost for purchase of 25kV electric power pack units and retrofitting diesel locomotives and cab control cars to operate with the electric power packs is approximately $4.0 million. It is possible that a modified, used electric locomotive could be a lower-cost alternative for the electric power pack, to the extent that they are available. New diesel locomotives would also be required to replace CalTrain's existing F-40 locomotives at a unit cost of $3.5 million.

Additional costs would be incurred for the installation of one substation (approximately $2.5 million) and the electrical distribution system, including two tie-breaker substations and the catenary ($4.2 million).

As presented in Table 2-1, the total capital cost for replacing/retrofitting 23 diesel locomotives and control cabs and adding 23 electric power packs using 25kV current is approximately $214 million. The total cost does not include the $80.5 million credit for replacing the entire diesel fleet, which would be funded from other sources. Neither AC nor DC electric power packs would be expected to have any resale value.

Operating and Maintenance (O&M) Cost

Additional operating expenses would be expected based on the slower speed and increased fuel requirements for hauling around the weight of the electric power pack. As indicated in Table 2-2, the electric power pack option would incur annual O&M costs of approximately $57.6 million, or about $2 million per year more than the dual mode locomotive and full system electrification options, for either 60-train or 86-train operating scenarios.

Implementation Schedule

Purchase of the electric power packs and new diesel locomotives would be expected in concert with DTX project implementation at the end of CalTrain's existing F-40 locomotive's life cycle (around 2005 to 2010). The electrification system would be installed as part of the downtown extension project.

Table 2-1

CAPITAL COST ESTIMATE FOR 25kV AC ELECTRIC POWER PACK OPTION

DESCRIPTION	UNIT	QTY	UNIT COST	FACTOR	TOTAL ($000)
CONSTRUCTION COSTS					
TRACTION POWER SYSTEM (SYSTEMWIDE)	EA	1.0	$6,723,161	1.00	$6,723
LOCOMOTIVES (SYSTEMWIDE)	EA	23.0	$7,500,000	1.00	$172,500
Subtotal CONSTRUCTION COSTS:					$179,223
NON-CONSTRUCTION COSTS					
ENGINEERING & MANAGEMENT					$6,856
Subtotal NON-CONSTRUCTION COSTS:					$6,856
CONTINGENCY					
CONTINGENCY				1.00	$19,966
PROJECT RESERVE					
PROJECT RESERVE				1.00	$7,859
TOTAL:					$213,904

Table 2-2

CALTRAIN O&M COST ESTIMATES FOR VARIOUS LOCOMOTIVE PROPULSION OPTIONS

	NO-BUILD		1.3- MILE EXTENSION TO TRANSBAY TERMINAL					
	CONVENTIONAL DIESEL		DUAL-MODE		ELECTRIC POWER TRAILER		STRAIGHT ELECTRIC	
CALTRAIN O&M ESTIMATE	60 TRAINS/ DAY	86 TRAINS/ DAY	60 TRAINS/ DAY	86 TRAINS/ DAY	60 TRAINS/ DAY	86 TRAINS/ DAY	60 TRAINS/ DAY	86 TRAINS/ DAY
ANNUAL O&M COST	$48,901,000	$60,630,000	$55,668,000	$68,603,000	57,584,000	$70,992,000	$55,619,000	$67,692,000
INCREMENTAL O&M COST	NA	NA	$6,767,000	$7,973,000	$8,683,000	$10,362,000	$6,718,000	$7,062,000
ANNUAL COST/PASS. TRIP	$5.94	$6.76	$4.96	$5.69	$5.13	$5.88	$4.96	$5.61
ANNUAL COST/TRAIN-HOUR	$1,759	$1,555	$1,933	$1,716	$1,999	$1,775	$1,931	$1,693
ANNUAL COST/CAR-MILE	$11.04	$9.76	$10.48	$9.23	$10.84	$9.56	$10.47	$9.11

NOTES:
(1) Costs estimated in 1995 dollars.
(2) Preliminary Operating & Maintenance Cost Estimates; CalTrain Downtown Extension Project; Peninsula Corridor Joint Powers Board; January 23, 1997.

3.0 DUAL MODE: DIESEL/ELECTRIC LOCOMOTIVES

3.1 MOTIVE POWER CHARACTERISTICS

Dual mode locomotives are locomotives that are capable of being powered by either a third rail or an overhead electric power source or an on-board diesel engine. Within the past year, two new manufacturers of dual mode, single-unit locomotives have delivered units in the United States. General Electric and Amtrak introduced the 10 P32 AC (Genesis) dual mode units to operate in the New York-to-Buffalo corridor. The P32 is a four-axle, 69-foot long, 264,000 lb. locomotive with a top operating speed of 110 miles per hour. Metro-North also ordered P32s to replace some of its EMD FL9 fleet, which was, until recently, the only dual power locomotive in North America. EMD countered with a new dual mode model that has similar performance characteristics to the P32. The Long Island Railroad has purchased 10 new EMD locomotives.

Both the P32 and the EMD dual mode locomotives have relatively conventional diesel engines and main alternators, but utilize inverter technology for AC traction and head-end power. Although the new generation locomotives receive electrical power from a third rail, a pantograph for power collection from an overhead source could be designed for either model.

For CalTrain, the P32 and EMD offer state-of-the-art locomotives specifically designed to perform in the subway/surface operating conditions being planned by the JPB. By housing the diesel and electric power source capabilities in one unit, this technology overcomes the issues related to weight, length, and performance (all of which have cost implications) inherent in the electric power pack concept. In addition, the P32 and EMD dual mode models share only one of the four fire and life/safety issues associated with the electric power pack option: the potential for the locomotive's diesel fuel tanks to rupture in the event of a train derailment.

More information regarding the characteristics of the dual mode single-unit locomotive is contained in the letters from Maurice M. Rix, Senior Engineer, LTK Engineering Services, and from Paul G. Eiben, Director of Engineering, Kaiser-EDA, Incorporated presented in Appendix C.

3.2 ELECTRICAL SYSTEM REQUIREMENTS

The P32 and EMD locomotives operate on a 1500V DC electric power supply system. A DC system for the downtown extension project requires two substations to supply power for subway operation and uses catenary. The DC electrical system, except for the catenary, would need to be replaced if the CalTrain system were converted to 25 kV AC in the future.

Dual mode locomotives using 25kV AC power supply have not been developed for performance reasons. Specifically, the step-down main transformer and associated equipment incorporated into the locomotive would make the locomotive heavier than

350,000 pounds and longer (thereby requiring triple axle trucks) than is able to negotiate the sharp 16-degree curves required for the DTX alignment.

More information about the 1500V DC electrification system is presented in Appendix A.

3.3 COST AND IMPLEMENTATION SCHEDULE

Capital Cost

Total system cost is estimated at $135 million, the lowest of all propulsion options being considered. Capital costs for 23 dual mode diesel/electric locomotives and the DC electrification system are identified in Table 3-1.

The unit cost of P32 or EMD locomotives is approximately $4.4 million. An $80.5 million credit for the replacement of the existing fleet is not included in Table 3-1 nor is the potential resale value of the dual mode locomotives if the system is converted to 25 kV AC before the end of their life cycle.

O&M Cost

The annual O&M cost for operating dual mode locomotives would be less than for the electric power pack option because of the reduced weight and length of the single-unit locomotives. Operating 60 trains per weekday with dual mode locomotives, the annual O&M cost estimate is approximately $55.7 million, or $1.9 million less than for the electric power pack option (refer to Table 2-2).

Implementation Schedule

Since the DTX project is not expected to be operational until after 2005, the purchase of dual mode locomotives would be expected to coincide with the end of CalTrain's existing F-40 locomotive's life cycle.

Table 3-1

CAPITAL COST ESTIMATE FOR 1500V DC DUAL MODE LOCOMOTIVE OPTION

DESCRIPTION	UNIT	QTY	UNIT COST	FACTOR	TOTAL ($000)
CONSTRUCTION COSTS					
TRACTION POWER SYSTEM (SYSTEMWIDE)	EA	1.0	$9,830,121	1.00	$9,830
LOCOMOTIVES (SYSTEMWIDE)	EA	23.0	$4,400,000	1.00	$101,200
Subtotal CONSTRUCTION COSTS:					$111,030
NON-CONSTRUCTION COSTS					
ENGINEERING & MANAGEMENT				1.00	$5,494
Subtotal NON-CONSTRUCTION COSTS:					$5,494
CONTINGENCY					
CONTINGENCY				1.00	$13,185
PROJECT RESERVE					
PROJECT RESERVE				1.00	$5,317
TOTAL:					$135,026

4.0 STRAIGHT ELECTRIC LOCOMOTIVES AND SYSTEMWIDE ELECTRIFICATION

4.1 MOTIVE POWER CHARACTERISTICS

Systemwide electrification refers to the use of 25kV AC to operate CalTrain along the entire 77-mile alignment from Gilroy to the proposed San Francisco Downtown Extension terminus. Conversion to 25kV AC represents the most expensive propulsion option to be carried forward. The systemwide conversion would involve the following components:

- Replacement of the existing F-40 diesel locomotives with AEM-7 (or equivalent) straight electric locomotives utilizing a 25 kV overhead power source;
- Implementation of a 25 kV AC traction power system;
- Installation of catenary (overhead wires) for power distribution; and
- Upgrading of the existing railroad signaling system in order to be compatible with electrification (note: power return currents would run through the same running rails that the signal currents now do).

Systemwide conversion would require replacement of the existing CalTrain diesel locomotives with 23 straight electric locomotives. American, European, and Japanese manufacturers produce state-of-the-art straight electric locomotives that would be suitable for subway/surface operation. Currently, AEM-7 7000 horsepower (diesel equivalent) electric locomotives are being used by Amtrak in the Northeast Corridor. The four axle, 51-foot long, AEM-7 is 201,000 lbs. A pantograph on the AEM-7 can extend up to 25.5 feet high. Maximum speed is 120 miles per hour.

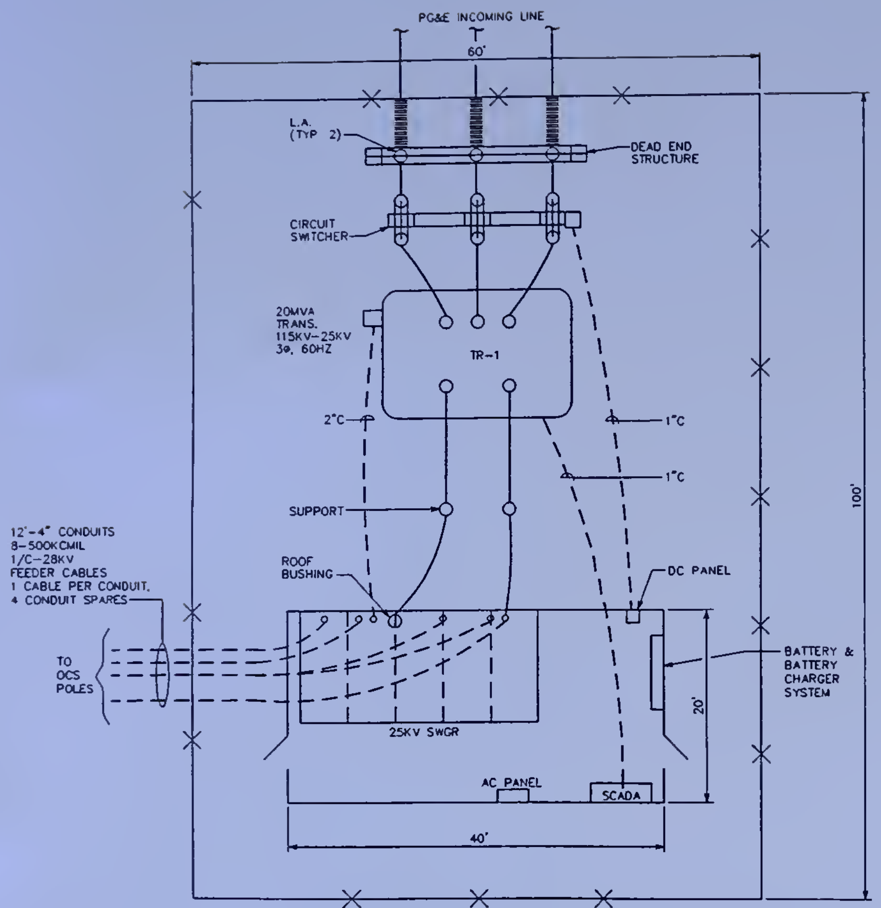
4.2 ELECTRICAL SYSTEM REQUIREMENTS

Traction Power System

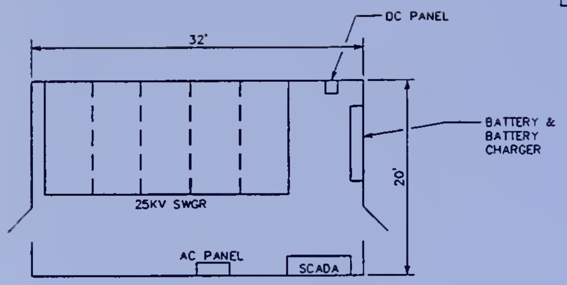
The 25kV AC single-phase, traction power electrification system would have five traction power substations and four tie breaker stations. They would be alternated along the CalTrain alignment (Figure 4-1). Substations and tie breakers would form a simple 25kV, single phase, radial, secondary selective traction power distribution (catenary) system. Additionally, three pairs of breaker stations, located at the proposed storage yard in Mission Bay, the proposed tunnel entrance in Mission Bay, and a yet-to-be-determined third location at a future rail yard in San Jose, would be required.

The pantograph, located on top of the locomotive, would deliver 25kV, single phase, 60 Hertz AC power to on-board propulsion equipment. On-board propulsion equipment would consist of a transformer, thyristor unit, and traction motors. Return current would follow the path of running rails and return feeders to the substation transformer.

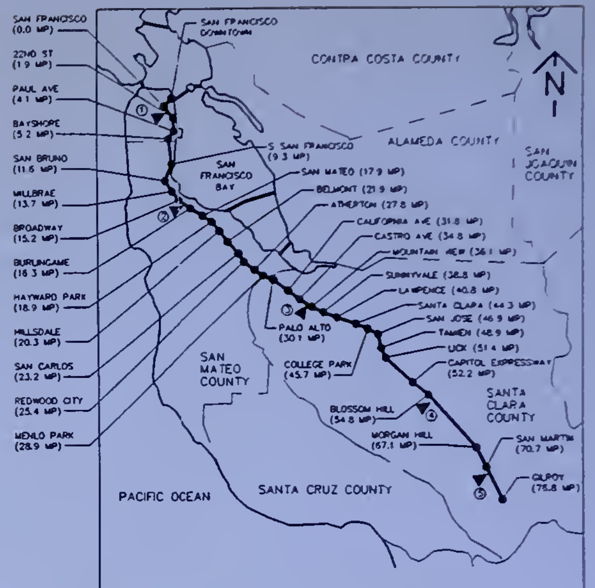
The JPB's consultants reviewed electrical demand with Pacific Gas and Electric (PG&E) representatives. In response to a request from PG&E to reduce adverse effects of single phase traction power load to their existing and planned power system supply, the traction power substations would contain Scott-connected power transformers to step-down



TRACTION POWER SUB.
N.T.S.



TIE BREAKER STATION
N.T.S



MAP OF CALTRAIN CORRIDOR
N.T.S.

▲ Tentative Location of TRACTION POWER SUBSTATIONS.

PRELIMINARY DESIGN

SUBJECT TO CHANGE

TYPICAL SUBSTATION EQUIPMENT LAYOUT

CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT

PENINSULA CORRIDOR JOINT POWERS BOARD

Figure 4-1
ELECTRIFICATION SYSTEM
TYPICAL SUBSTATION & TIE BREAKER STATION EQUIPMENT LAYOUT

◆ ICF KAISER/DELEUW

PG&E three-phase primary power supply. More information regarding the 25 kV AC electrification system is presented in Appendix B.

Catenary

The selection of catenary type is influenced by the category of track for the CalTrain system. Currently the maximum train speed on the existing system is in the order of 70 miles per hour (mph) or 79 mph maximum for FRA Class 4 track. It is envisioned that equivalent speed would be retained after electrification. A simple catenary auto-tensioned with sagged contact wire is suitable for a wide range of train speed (25 mph to over 100 mph) to transfer electrical energy from the catenary to the pantograph. This type of catenary is in operation with train speeds in excess of 100 mph on some European and Japanese electrified lines. Simplicity (inexpensive to maintain and operate) and efficiency (dynamic attributes) make it the consensual preference for most electrified railroad and transit systems.

In the subway, where solar heating to the overhead contact wires is not a factor and the ambient temperature range is relatively low, a simple catenary fixed termination system would be used. The temperature variation in the overhead wire is minimal since contact wire heating is mainly due to load current. As a result, the effect of sag in the system is lower. A fixed catenary could be used in the tunnel because trains would operate at low speed (10 mph minimum to 30 mph maximum). At this low speed, sagging and loss of tension in the contact wire translates to an inconsequential effect in the dynamics of the catenary. A fixed system in the tunnel also eliminates the need for providing extra supports to accommodate the catenary in a limited space in the tunnel.

In the proposed new train storage yard, a single-wire, fixed termination system would be used where train speed is low and system dynamics is not constrained.

Signaling System

For this propulsion option, CalTrain's existing 40-year old railroad signaling system would be rehabilitated to make it compatible with the 25kV AC electrical system because the return power current would utilize the same running rails as the railroad signalizing system now does. The cost estimate does not include upgrading the Centralized Traffic Control (CTC) system, although the full upgrade is recommended to improve CalTrain operations and efficiency.

The following assumptions were made for the signal system as part of the CalTrain full system electrification option:

- The signal system would be rehabilitated to be compatible with CalTrain system electrification (an entirely new signal system would cost significantly more);
- No special effort would be made to reduce the rail-to-ground resistance, as would normally be done for a new electrified system;

- The existing signal system block lengths would remain acceptable for the braking characteristics, speed, and operation of the electrified CalTrain system;
- Sufficient space would be available in the signal equipment houses and for signal equipment cases for the new track circuit equipment necessary to adapt the existing system to 100 Hertz or phase shift overlay II track circuits;
- An outside contractor would modify equipment, install cable, install signal bridges, and install cases in a timely manner; the JPB would perform the final cutover and testing; and
- Rail would be continuously welded, across all joints, except at special trackwork areas such as freight sidings or crossovers.

4.3 COST AND IMPLEMENTATION SCHEDULE

Capital Cost

As indicated in Table 4-1, the total capital cost estimate for full system electrification is approximately $278 million. The unit cost for the AEM-7 electric locomotive is $4.8 million or slightly higher than the dual mode locomotives. Because of the length of the CalTrain alignment, systemwide conversion to 25kV AC approximately doubles the total capital cost for this option over the dual mode option. An $80.5 million credit for the replacement of the existing fleet of locomotives is not included in the table.

O&M Cost

Full systemwide electrification would reduce fuel and locomotive maintenance costs and increase locomotive performance. However, the extensive 77-mile long electrification system would require increased wayside maintenance costs. Operating 60 weekday trains with electric locomotives would have an annual O&M cost of approximately $55.6 million, or $48,000 less than the dual mode option and $1.96 million less than the electric power pack option (refer to Table 2-2).

Implementation Schedule

The costs presented in Table 4-1 assume the entire system would be converted to 25kV AC operation when the DTX project is implemented.

Table 4-1

CAPITAL COST ESTIMATE FOR THE STRAIGHT ELECTRIC LOCOMOTIVE WITH 25KV AC SYSTEMWIDE ELECTRIFICATION OPTION

DESCRIPTION	UNIT	QTY	UNIT COST	FACTOR	TOTAL ($000)
CONSTRUCTION COSTS					
TRACTION POWER SYSTEM (SYSTEMWIDE)	EA	1.0	$70,484,496	1.00	$70,484
SIGNALING - WAYSIDE AND STATION	LS	1.0	$20,100,000	1.00	$20,100*
YARDS & SHOPS (SYSTEMWIDE)	EA	1.0	$500,000	1.00	$500
LOCOMOTIVES (SYSTEMWIDE)	EA	23.0	$4,800,000	1.00	$110,400
Subtotal CONSTRUCTION COSTS:					$201,484
NON-CONSTRUCTION COSTS					
ENGINEERING & MANAGEMENT				1.00	$26,083
Subtotal NON-CONSTRUCTION COSTS:					$26,083
CONTINGENCY					
CONTINGENCY				1.00	$35,503
PROJECT RESERVE					
PROJECT RESERVE				1.00	$15,526
TOTAL:					$278,596

* This dollar amount represents the minimum signal system upgrade necessary for systemwide electrification as identified in the CalTrain San Francisco Downtown Extension Project *Preliminary Capital Cost Estimates* (Joint Powers Board, September 1996)

5.0 SUMMARY EVALUATION AND RECOMMENDATIONS

5.1 SUMMARY EVALUATION

This section compares characteristics of the three locomotive propulsion options being considered for the CalTrain DTX project: Dual Mode Electric Power Packs, Dual Mode Locomotives, and Straight Electric Locomotives with 25kV AC Full System Electrification.

Motive Power Characteristics

A locomotive's performance is affected by its weight, length, and tractive capabilities of the propulsion units. In this regard, superior performance characteristics are offered by both single-unit dual mode locomotives and straight electric locomotives. For these locomotives, the motive power apparatus is contained in a single unit, minimizing their length and weight. Because of their relatively lighter structure, their acceleration and speed are greater than the electric power pack option with its locomotive and attached power trailer car.

Additionally, dual mode and electric locomotives offer greater reliability. Electric power packs are more complex and, therefore, may require more maintenance hours and spare parts.

Electrification Requirements

The JPB's long-term goal is to use 25kV AC power supply systemwide. An electrification system using 25kV AC offers more efficient power transmission capabilities (less line losses) and requires fewer substations, which are a significant capital expenditure. The straight electric locomotive and the AC power pack options conform with the JPB's long-term goal. The former requires systemwide electrification; the latter represents the initial step toward full electrification.

The dual mode locomotive option is not consistent with the JPB's long-term goal for 25kV AC electrification. DC facilities and the dual-mode locomotives would become obsolete when AC conversion occurs (although the dual mode locomotives will have some salvage value).

Capital Costs

The dual mode locomotive option has the lowest total capital cost, approximately $135 million; the electric power pack option at nearly $214 million is second; and due to the new signaling and electrification system requirements, the full system electrification option has the greatest capital cost at approximately $279 million, or $144 million more than the dual mode option.

Motive Power Cost -- Dual mode locomotives represent the least costly motive power option, with a unit cost of $4.4 million. Straight electric locomotives are slightly more expensive at approximately $4.8 million. The most expensive costs are for the combined purchase of electric power packs and new diesel locomotives at $7.5 million per combination unit.

Electrification Cost -- The cost of the AC electrification system for the electric power pack option is approximately $6.7 million. The cost for the DC electrification for dual mode locomotives is $9.8 million. The most expensive electrification cost would occur for systemwide electrification because of the 77-mile length of the system and minor rehabilitation of the signaling system. Signaling upgrade improvements would not be required for the other two options since the electrification system would be installed only in the new DTX subway and approach tracks.

Operations and Maintenance Costs

The lowest O&M costs will be achieved through full system electrification, although all three options are within four percent of each other. Dual mode is second and the electric power pack option is the most expensive in terms of O&M costs (refer to Table 2-2).

For full system electrification, annual O&M costs are expected to be $55.6 million (60 daily trains) and $67.7 million (86 daily trains). For dual mode locomotives, annual O&M costs are expected to be slightly lower at $55.7 million (60 daily trains) and $68.6 million (86 daily trains). For electric power packs, annual O&M costs are expected to be $57.6 million (60 daily trains) and $70.1 million (86 daily trains).

Implementation Schedule

The timing of the CalTrain DTX project implementation should coincide closely with the completion of CalTrain's existing F-40 locomotives' life cycle (approximately 25 years following their purchase in 1985), allowing the replacement of the entire fleet and an $80 million credit to the capital cost of all propulsion options.

5.2 RECOMMENDATIONS

The recommendation for the evaluation of CalTrain propulsion options is based on the following assumptions:

- DTX project implementation would coincide closely with the normal replacement of CalTrain's existing F-40 locomotives;
- Funding for full system electrification will not be available as part of the DTX project; therefore, CalTrain system electrification will occur in phases; and
- A least-cost interim solution for electric operation in the CalTrain DTX subway is preferred.

Given these assumptions, the preferred option would be replacing CalTrain's existing locomotives with dual mode locomotives, as an interim phase until funding for full system electrification conversion could be secured.

Dual mode locomotives would offer capital and O&M cost advantages compared with the electric power pack option, which would require the acquisition of new diesel locomotives and new power packs. In addition, because motive power is produced within a single unit, the performance characteristics of the dual mode locomotive are superior to the electric power pack option.

Ultimately, dual mode locomotives and the DC electrification system facilities, excluding the poles and the catenary system, would need to be replaced by locomotives and electrification system facilities that operate with a 25kV AC power supply. Conversion to AC would require purchase of new straight electric locomotives, but the existing dual mode locomotives could be resold. They could be used either as conventional diesel-electric locomotives or dual mode locomotives should conversion take place before the end of the dual mode locomotives' useful life.

Recommendations of individual experts asked to comment on the Caltrain dual made power pack and electrification options are included in Appendix C.

CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT

EVALUATION OF CALTRAIN LOCOMOTIVE PROPULSION OPTIONS

APPENDICES

APPENDIX A

CALTRAIN SAN FRANCISCO DOWNTOWN EXTENSION PROJECT 1500 V DC ELECTRIFICATION ANALYSIS REPORT

PREPARED FOR

PENINSULA CORRIDOR JOINT POWERS BOARD

Prepared by

ICF KAISER ENGINEERS, INC
OAKLAND, CAL

Issued
June, 1996

R65928X-051971-1

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CALTRAIN/PCS RAILROAD ELECTRIFICATION SYSTEM 1500 V DC FOR DOWNTOWN SAN FRANCISCO

1.0 GENERAL

This report briefly describes the major components of the 1500 volts DC electrification system for the dual mode locomotive option for the purpose of cost estimation. The data contained in this report is based upon the concept that the dual mode locomotive will be switched from diesel fuel power to 1500V DC overhead electric power before the train enters into the downtown tunnels and vice versa. Overhead Contact System (OCS) components designed for the ultimate 25 kV single phase AC electrification system will be used with the change of messenger wire to accommodate the increase in the electrification current at 1500 V DC as compared to 25 kV AC current. DC electrification system will cover approximately 4 miles of main-line tracks starting from the downtown San Francisco terminal station and approximately 1.5 miles of yard storage tracks under consideration at the 16th and Owens Streets.

2.0 TRACTION POWER SYSTEM - 1500V DC

Propulsion system power requirements for this study are based upon using the dual mode locomotive GE Model P32AC-DM which utilizes AC propulsion motors with on board inverters for pulse width modulation characteristics to convert DC to AC power as required. Modification of the GE Model P32AC-DM is required to operate on 1500V DC to be supplied from overhead catenary system.

Electrification system of the line diagram SK1-DC indicates the major components of the DC traction power system. PG&E incoming primary power supply at 34.5 kV level will be converted to 1500V DC by the diode rectifier conversion units.

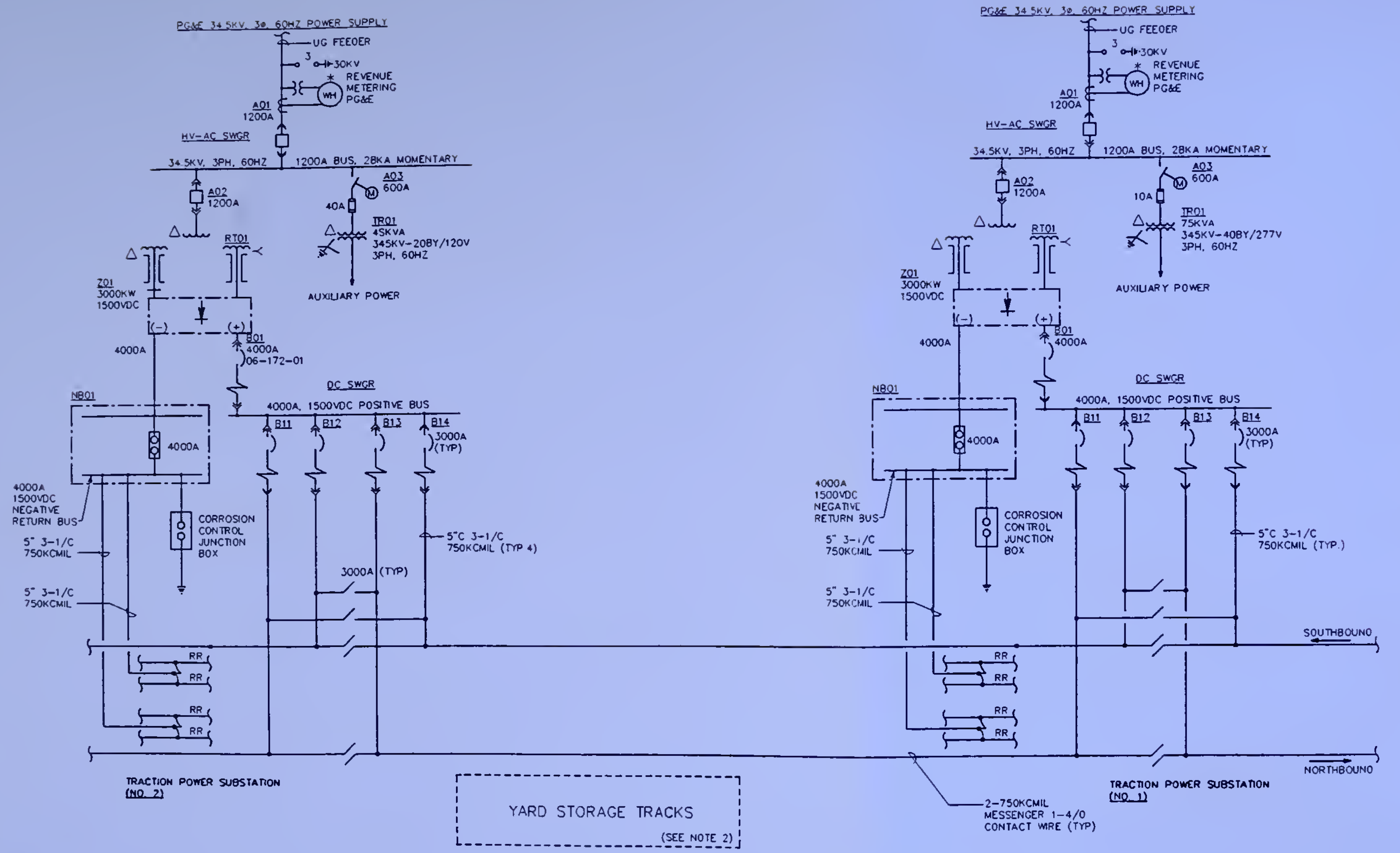
Pre-fabricated outdoor type housing will accommodate all traction power substation equipment consisting of: 1) 34.5 kV switchgear; 2) 3000 kW transformer & rectifier (T-R) unit with 12 pulse 1500V DC output; 3) 1500V DC switchgear; 4) 4000A negative bus-box; 5) 75 kVA dry type auxiliary power transformer; and 6) all other substation auxiliary components such as battery and battery charger, annunciator panel, corrosion control cabinet etc.

Incoming AC primary power supply and outgoing DC power supply feeders will be installed in underground duct banks in accordance with each site specific requirements. Incoming power supply feeder cables will be rated at 35 kV, single conductor, shielded EPR insulation. Single conductor non-shielded 5 kV EPR insulated cable will be used for DC feeders between the substation housing and the OCS. Single pole no-load

NOTES.

1 * DENOTES FURNISHED AND INSTALLED BY PG&E

2 SECTIONALIZING DC DISCONNECT SWITCHES FOR MAINLINE & STORAGE TRACKS IS NOT SHOWN FOR CLARITY OF THIS DRAWINGS



CALTRAIN/PCS RAILROAD–1500V DC, ELECTRIFICATION SYSTEM ONE LINE DIAGRAM

CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT

PENINSULA CORRIDOR JOINT POWERS BOARD

1500V DC ELECTRIFICATION SYSTEM
ONE LINE DIAGRAM

SCALE: NOT TO SCALE
DATE: 05-21-96
DESIGNED BY: DEV PAUL
DATE: ______
CHECKED BY ______
DWG. NO.
SK1-DC

disconnect switches each rated at 3000A, 1500V DC in fiberglass enclosure will be used for sectionalizing the yard and the mainline tracks as required.

Two pre-fabricated traction power substations will be provided based upon the preliminary engineering analysis for cost estimation purposes. Refer to drawing SK2-DC for tentative location and physical dimensions of the substations. Under abnormal system operation when one traction power substation is out of service, the second substation will be able to maintain the train operation with slight degradation in performance.

3.0 POWER SYSTEM PROTECTIVE DEVICES

Appropriate AC and DC protective devices will be applied to the power system to have adequate protection to the equipment and safety of the general public in accordance with industry practice. The transformer will be equipped with winding temperature relays.

4.0 OCS SYSTEM VOLTAGE RANGE

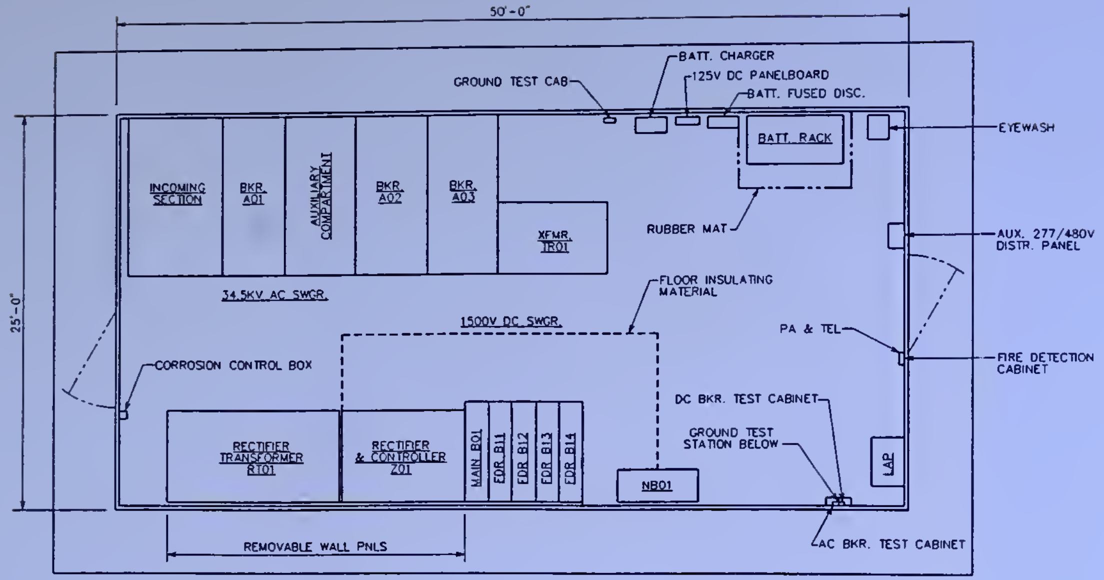
Traction electrification system will be designed with the following OCS voltage limits;

Nominal OCS operating voltage:	1.5kV
Maximum OCS voltage limit	1.59 kV
Minimum operating voltage under normal system operation:	1.05 kV
Minimum voltage limit under exceptional conditions:	1.0 kV

These voltage limits will be confirmed and coordinated with the locomotive electrical characteristics in detailed design stage.

5.0 POWER FACTOR CORRECTION CAPACITORS AND HARMONIC FREQUENCY FILTERS

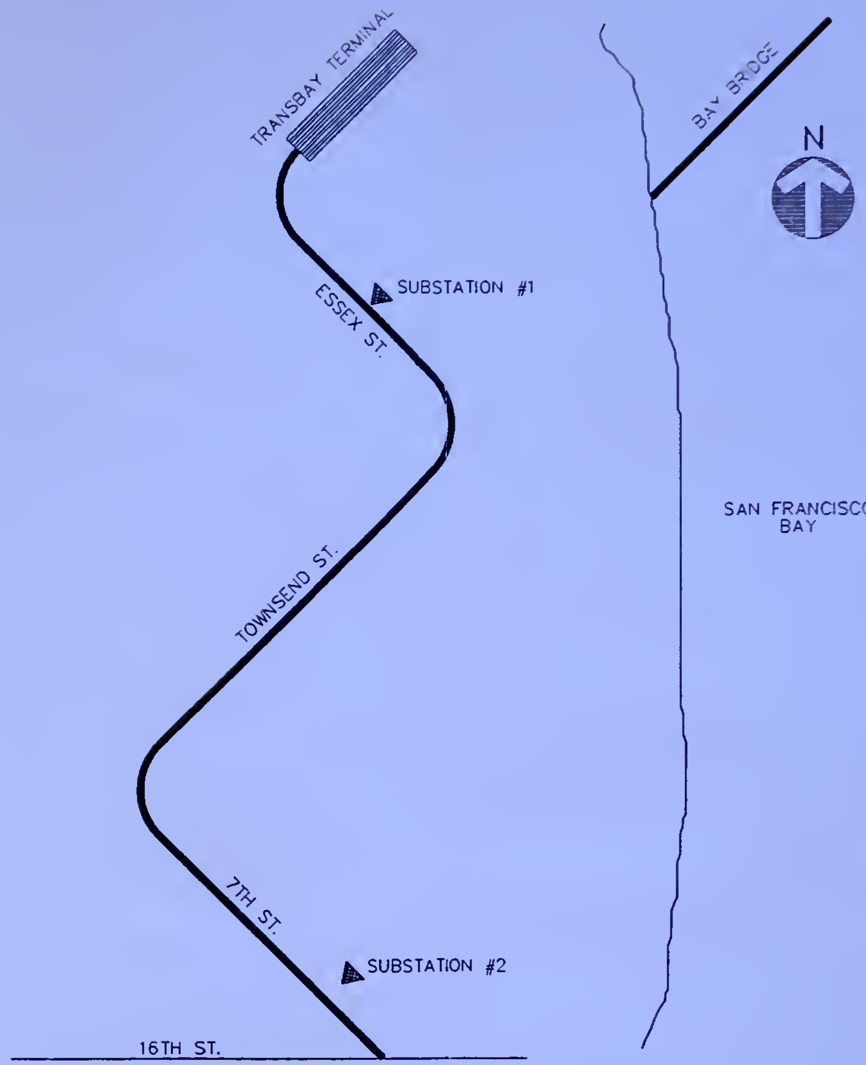
Requirements of power factor correction capacitors and harmonic frequency filters will be determined by power system analysis using the utility company power system data at the supply points and the locomotive motor characteristics. The analysis will occur in the detailed design phase of the project. An allowance has been made to cover the cost of the equipment, if required.



PLAN

PREFABRICATED TRACTION POWER SUBSTATION

NTS



MAP OF 1500V DC SUBSTATION LOCATIONS

NTS

CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT

PENINSULA CORRIDOR JOINT POWERS BOARD

ELECTRIFICATION SYSTEM
1500V DC TRACTION POWER

SCALE: NOT TO SCALE
DATE: 05-21-96
DESIGNED BY: DEV PAUL
DATE:
CHECKED BY:
DWG. NO.
SK2-DC

6.0 TRACTION CURRENT RETURN SYSTEM AND CORROSION CONTROL

Traction current will be returned from the locomotives to the substations via running rails. The four running rails will be crossbonded. Running rails will be insulated from the ground by using appropriate insulating fastening systems. The extent of corrosion on underground utilities due to DC leakage current is a major concern of the DC electrification system. Underground utilities along the right-of-way will be evaluated to determine the need for corrosion protection.

The traction power system will be operated ungrounded. There will be no intentional connection between the DC power supply system components and the ground except through the instruments, the DC surge arresters, and the high resistance protective relay scheme at the substation.

Allowance has been made for the installation of corrosion control test stations along the tracks in the tunnel structure for measurement of leakage currents prior to and during system operation.

7.0 SUBSTATION GROUND GRID

Each traction power substation housing will be completely fenced for public safety. Substation ground grid will be designed to have 5 ohms or less ground grid resistance to remote earth. The grounding system will consist of 4/0 bare copper conductor and appropriate number of 5/8 x 8 feet copper clad steel ground rods. Crushed rocks will be used to cover the surface layer for personnel safety. AC switchgear enclosure, the rectifier transformer enclosure, the auxiliary transformer, and the substation enclosure will be grounded to the ground grid for personnel and equipment safety. DC surge arresters will be connected to the ground through the isolated ground rods. Provision will be made for the connection of the leakage current detection drain wires to the corrosion control box at the substation.

8.0 UTILITY METERING FACILITIES

The substation metering facilities and the support structure needed to accommodate the utility metering equipment are included.

1500V DC ELECTRIFICATION

Attachment 1

CALTRAIN ELECTRIFICATION PROJECT
DUAL MODE LOCOMOTIVE
1500V DC OVERHEAD CATENARY SYSTEM

PRELIMINARY ENGINEERING ANALYSIS
TRACTION POWER SUBSTATIONS

traindc

CALCULATION NO. 1

DUAL MODE LOCOMOTIVE (DIESEL AND 1500 V DC) ESTIMATED VALUE OF DC TRACTION POWER DEMAND BASED UPON ENERGY CONSUMPTION (kWH/CAR - MILE), TRAIN OPERATING SCHEDULE AND DISTANCE

Approximate distance from San-Francisco Terminal station to end of dc electrification = 4.0 miles

During peak hour operation total of 17 trains are considered in the system. Eight 7-car trains and nine 5-car trains (total of 101 cars) on both tracks. The energy consumption for a 4-car train is indicated as 47 kWH/mile in MK report dated Oct. 1992. Train travel time between San Francisco to Gilroy is in the order of 6770 seconds (approximately 1.88 hours). Thus the train headway considering seventeen trains in the peak hour will be in the order of 6.6 minutes (1.88 x 60 / 17), use 6.5 minute for this calculation..

kWH/ Car - mile = A

Therefore :

kW= A x (Car - miles)/ Hour

Cars/ Hour = (60/ Headway in minutes) x (Cars/ Train)

Car - miles/Hour = 2 x 4.0 miles x (60/ Headway in minutes) x (Cars/ Train)

Car - miles/Hour = 2 x 4.0 x (60/6.5) x 6 = 443

Considering A = 11.75

kW = 11.75 x 443 = 5206

Please note that each train is considered to be six car train to compute Cars/hour in operation. The calculated value of kW power requirement is in the order of 5.2 MW. If the headway is considered to be six minutes then required power will become 5.6 MW. For six car train the specific value of energy consumption will be slightly greater than the value of 11.75 used in the above calculation. Thus two traction power subsations each rated at 3.0 MW shall be considered based upon the fact that switching from diesel fuel to electric may overlap some of the distance considered in 4 miles of dc electrification.

vdtrain7

CALCULATION NO.2

CALTRAIN ELECTRIFICATION PROJECT
1500 V DC POWER SUPPLY SYSTEM
4.0 MILES OF TRACK ELECTRIFICATION STARTING FROM SAN-FRANCISCO DOWN TOWN TERMINAL STATION

A. System Parameters

1. Rectifier unit equivalent impedance in ohms

$PU := 0.06 \qquad KV := 1.5 \qquad MW := 3.0$

$Z_r := \frac{PU \cdot KV^2}{MW} \qquad Z_r = 0.045$

2. Running rails specific impedance in ohms/mile, all four rails in parallel

$N := 4 \qquad r_r := \frac{6}{N \cdot 150}$

$r_r = 0.01$

3. Overhead Contact Wire system (OCS) equivalent resistance in ohms/mile/track. Messenger wire 2- 750 KCMIL H. D copper and contact wire 4/0 H.D copper

$r_{mw} := \frac{0.0832}{2} \qquad r_{cw} := 0.2963$

$r_{ocs} := \frac{r_{mw} \cdot r_{cw}}{r_{mw} + r_{cw}} \qquad r_{ocs} = 0.036$

4. Train starting current assume 3500A for five car trains with a locomotive and running train with current of 2000A.

$I_1 := 3000 \qquad I_2 := 1500 \qquad I_3 := 0 \qquad I_4 := 200$

$D_1 := 2.5 \qquad D_2 := 0.9 \qquad D_3 := 0.1 \qquad D_4 := 0.1$

$I := I_1 + I_2 + I_3 + I_4 \qquad r := r_{ocs} + r_r$

$V_d := Z_r \cdot I + r \cdot I \cdot 0.1 + \left[r \cdot \left(I_1 + I_2 \right) \cdot 0.8 + r \cdot I_1 \cdot 0.9 \right]$

$V_d = 526.159$

$V_1 := 1.06 \cdot 1500 - V_d$

$V_1 = 1.064 \cdot 10^3$ Min. acceptable voltage 1000V

JOB NO. 65928-004

SHEET 1 OF 1

CALTRAIN ELECT. PROJECT.
1500V DC ELECT. SYSTEM

DESIGNED BY D. PAUL DATE 5/10/96

CHECKED BY DATE

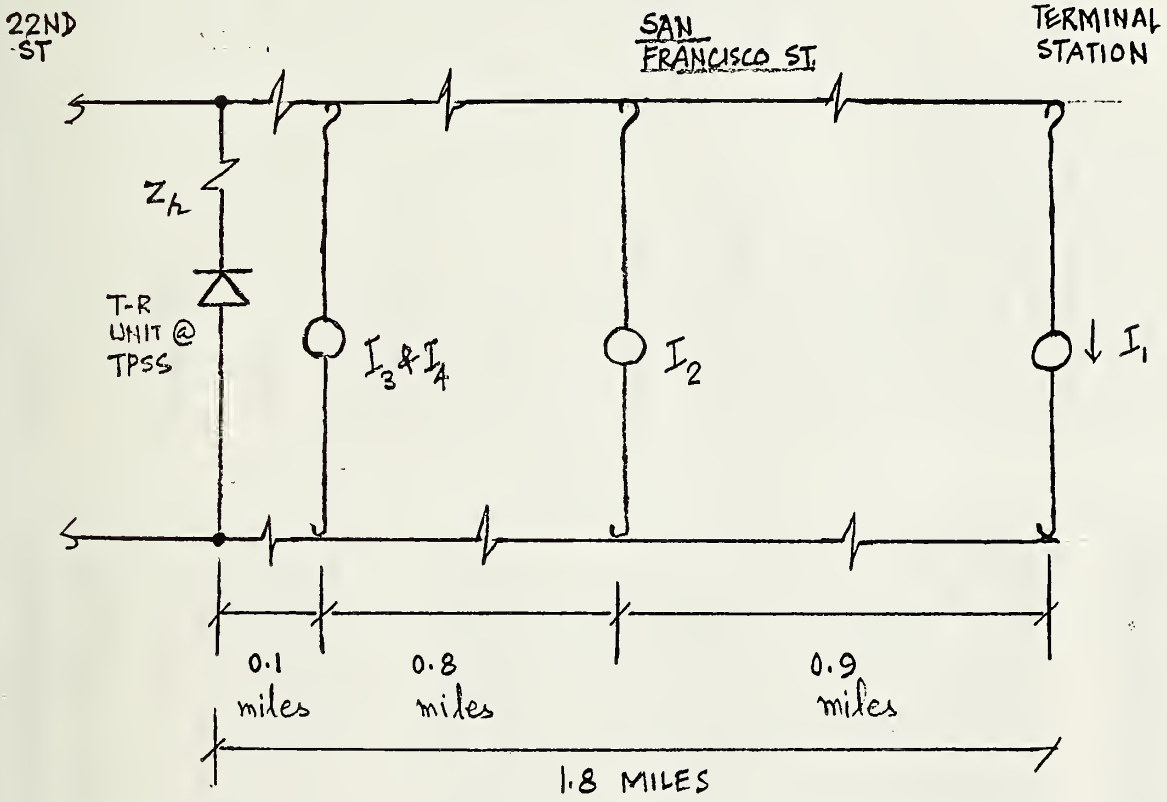


FIG. 1: TRAIN CONFIGURATION AND IMPEDANCE DIAGRAM FOR TRAIN STARTING VOLT. DROP CALCULATION

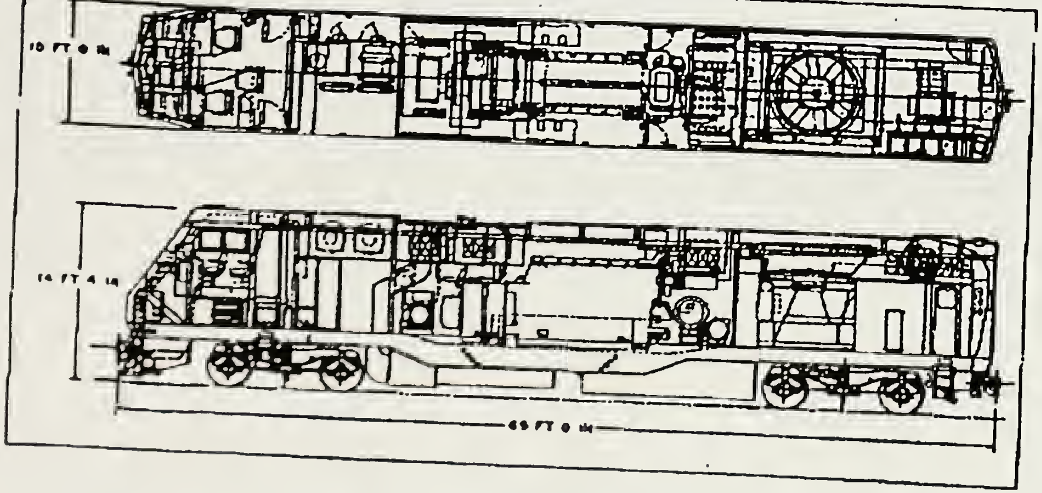
Advanced-Design AC Passenger Locomotive Delivers High Performance from Diesel and from Third Rail Power

GE Transportation Systems' new advanced-design dual mode passenger locomotive is strikingly contemporary in styling and packed with advanced technology specifically designed for reliable, high-speed passenger service on Amtrak's system. The P32AC-DM operates in diesel or third rail power and delivers unsurpassed performance in either mode. It can quickly accelerate five Amfleet cars to over 110 mph in diesel mode and to over 60 mph when operating on third rail mode in New York City tunnels.

Built-in redundancy with special emphasis on the design of the Head End Power system enhances mission reliability. For example, with GE's innovative air-cooled, inverter-per-motor AC propulsion system, the #1 traction inverter provides automatic back-up to the HEP inverter. In the back-up mode, the locomotive will continue to operate at full-rated horsepower.

The system computers automatically control the transition between power modes. This transition is "seamless" and provides uninterrupted hotel power to the train. Power for lighting, air conditioning, heating and other train services remains "on" during the transition to provide passenger comfort and security.

GE Transportation Systems . . . Dedicated to Customer Success™



GENESIS™ Series 2 Specifications

Model	P32AC-DM – 110 mph, 3200 hp, 800 kW HEP, with Dual Power 650 VDC third rail capability
Arrangement	B-B – Trucks fitted with 6 third rail power pick-up mechanisms
Weight	274,400 lb.
Engine Model	7FDL12, 3200 hp with EFI
Traction Equipment	
• Alternator	1 – GMG195A1
• Motors	4 – GEB15 AC, axle suspended
• Inverters	4 – Pulse width modulated, VVVF, one per traction motor for single axle control
Head End Power	Inverter rated 800 kW, 480 V, 3 Phase, 60 Hz
Air Brake Schedule	26L Integrated Electronic Air Brake Control by NYAB/Knorr
Air Compressor	1 – Sullair 8E Rotary

Configuration and Features

- Aerodynamic monocoque carbody
- Enhanced collision capability
- Cab signal equipped – Micro Cabmatic® by GRS
- Microcomputer-based integrated control, full diagnostics
- Engine layover system by Kim Hot Start
- Segmented, spill-resistant fuel tank
- Automatic parking brake
- Remote engine starting
- Retractable third rail shoes
- Blended dynamic/air brake system
- Dual mode with seamless transition
- Hostler stand
- Battery jog capability

APPENDIX B

CALTRAIN SAN FRANCISCO DOWNTOWN EXTENSION PROJECT 25 KV AC ELECTRIFICATION ANALYSIS REPORT

PREPARED FOR

PENINSULA CORRIDOR JOINT POWERS BOARD

Prepared by

ICF KAISER ENGINEERS, INC
OAKLAND, CAL

Issued
June, 1996

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CALTRAIN/PCS RAILROAD
ELECTRIFICATION SYSTEM
FROM GILROY TO SAN FRANCISCO

1.0 INTRODUCTION

This report briefly describes the major components of the 25 kilovolt (kV) single phase ac electrification system for the purpose of cost estimation. The data contained in this report is based upon information provided in *Electrifying the Caltrain/PCS Railroad* prepared by Morrison-Knudsen Engineers for the Joint Powers Board (JPB) in October 1992. The limited information on existing signalling system was gathered through conversations with JPB staff.

An attempt has been made to identify the major components of each subsystem from a cost estimation point of view. These subsystems are as follows:

- Traction power - 25 kV ac system
- Overhead contact system (OCS)
- Signalling system
- Communication system

Various subsystem components indicated in the report and used for cost estimation were selected based upon the technical judgement, industry practice, and past performance of the equipment. However, without the complete knowledge of the sectionalization scheme for the mainline track and the maintenance storage yards, the assumptions that were made for the equipment required for system electrification could change in the design phase. To confirm that the PG&E power supply system would be able to meet the required single phase traction power system demand load at the tentative substation locations, two technical meetings took place with PG&E (see Attachment 1). PG&E preferred to supply three phase power at each traction power substation in order to reduce adverse effects (phase unbalance and negative sequence currents) of single phase traction power load to their existing and planned power supply system. Thus Scott connected power transformer will be used at each traction power substation location to step down PG&E three phase primary power supply to two phase power at required 25 kV level to use as single phase.

A trade off analysis, communications with power utility companies, extent of cathodic protection requirements, and field surveys would occur in a subsequent phase of the study.

2.0 TRACTION POWER - 25 kV SINGLE PHASE

A brief description of the 25 kV AC traction power electrification system, which would be implemented for CalTrain operations is provided below.

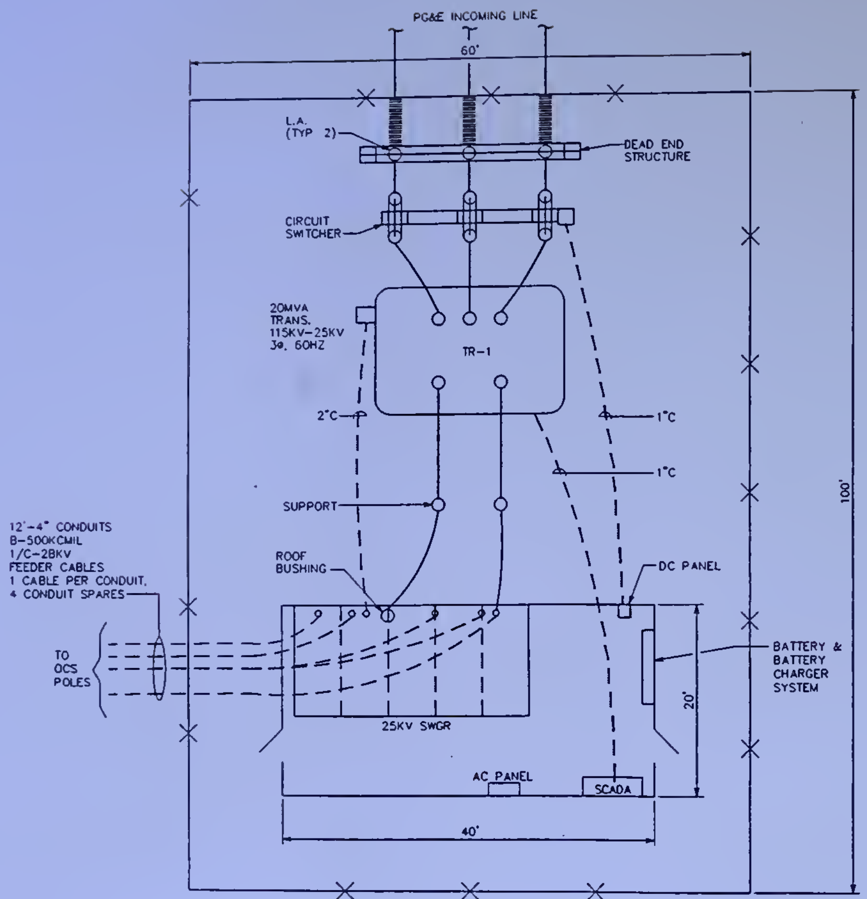
2.1 ELECTRIFICATION SYSTEM MAJOR COMPONENTS

Five traction power substations and four tie breaker stations would be alternatively located along the double track alignment (Figure 1). Substations and tie breakers would form a simple 25 kV, single phase, radial, secondary selective traction power distribution (catenary) system. Additionally, three pairs of breaker stations, located at the proposed storage yard at 16th/Owens Streets in Mission Bay, Pullman Yard in San Jose, and the proposed tunnel entrance in Mission Bay, would be required for system electrification. Scott connected, three phase to two phase, 60 hertz (Hz), 20/26.6/35.4million volt ampere (MVA), oil air/fan air/fan air (OA/FA/FA), 65 degree centigrade temperature rise oil filled transformers would be provided at each substation to convert the PG&E supply voltage to 25 kV, single phase, 60 Hz.

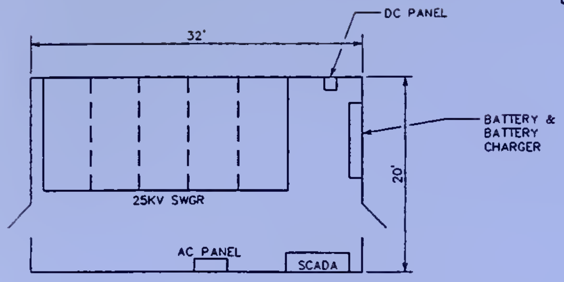
The catenary system would consist of 4/0 bare copper contact wire, 350 kilo circular mil (kCMIL) bare copper messenger wire and the 4/0 stranded aluminum conductor steel reinforced (ACSR) return wire supported by appropriate poles and associated components. Because of the traction load fluctuations, the power transformers would be specified to supply rated power continuously with a superimposed load cycle equal to 150% of continuous load for 2 hours and 300% of continuous load for 5 minutes without significant reduction of service life expectancy. The pantograph (collector), located on the locomotive, would deliver 25 kV, single phase, 60 Hz power to on-board propulsion equipment. On-board propulsion equipment would consist of transformer, thyristor unit, and traction motors. Return current would follow the path of running rails and return feeders to the transformer secondary.

At each traction power substation, dead end structure would be required to terminate PG&E 115 kV incoming overhead supply conductors (Figure 2). Overvoltage surge arresters and appropriate insulators along with other supporting members would be installed. The design would comply with American National Standard Institute (ANSI) safety code C2 and GO95 for all clearances for the safety of maintenance personnel. Standard three pole circuit switcher rated 1200A, 115 kV would be used as a primary switching device to the power transformer. Protective relays would be properly selected and set to automatically operate the circuit switcher in case of fault.

1200A, 25 kV, walk-in aisle type, metalclad switchgear complete with drawout type single pole circuit breakers, load interrupter switches, fuses, relays, auxiliary power transformer, battery system would be used to transmit power to the OCS system. Switchgear enclosure would have roof-mounted bushings for 25 kV incoming feeder connections and stress cone connections for the outgoing feeders to the OCS system. Minimum basic impulse level (BIL) for the 25 kV equipment would be 150 kV peak. Appropriate outdoor structure would be used to support the bus work for connecting the switchgear to the transformer. An underground duct bank would be provided for feeder cables to connect the switchgear to the OCS system.

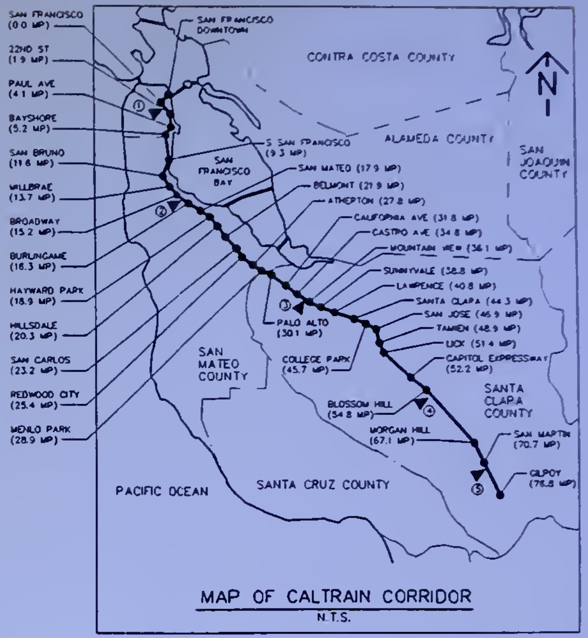


TRACTION POWER SUB.
N.T.S.



TIE BREAKER STATION
N.T.S.

TYPICAL SUBSTATION EQUIPMENT LAYOUT



MAP OF CALTRAIN CORRIDOR
N.T.S.

▲ Tentative Location of TRACTION POWER SUBSTATIONS.

PRELIMINARY DESIGN

SUBJECT TO CHANGE

CALTRAIN SAN FRANCISCO
DOWNTOWN EXTENSION PROJECT

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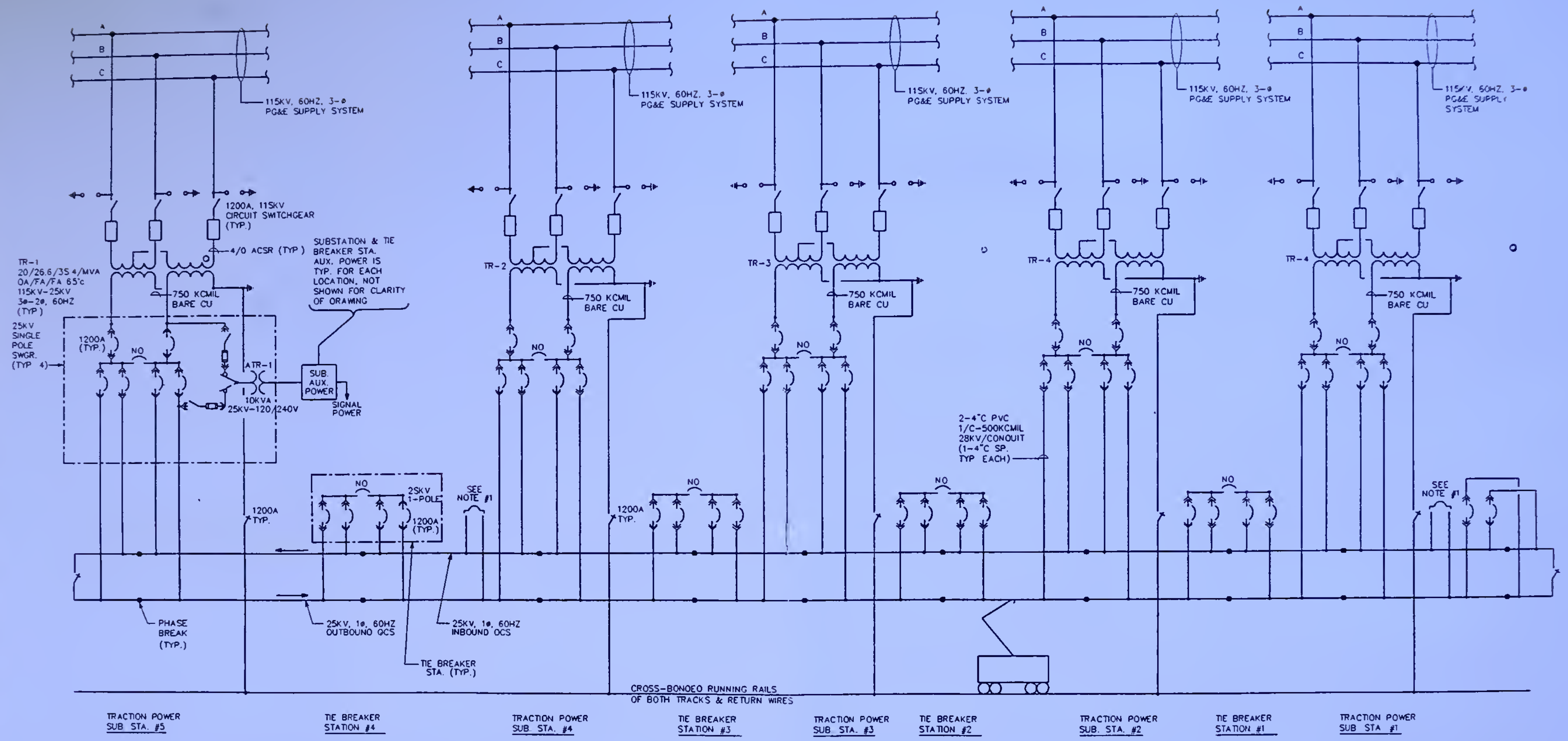
Figure 1
ELECTRIFICATION SYSTEM TYPICAL SUBSTATION & TIE BREAKER STATION EQUIPMENT LAYOUT

◆ICF KAISER/DELEUW



CALTRAIN/PCS RAILROAD-25KV, 1φ, 60HZ ELECTRIFICATION SYSTEM ONE LINE DIAGRAM

NOTE.

1 BREAKER STATION CONSISTING OF GROUP OF TWO (2) BREAKERS REQUIRED FOR YARD POWER FEED IN THIS AREA IS NOT SHOWN FOR CLARITY OF DWG. PRESENTATION.

PRELIMINARY
DESIGN
SUBJECT TO CHANGE

Figure 2
ELECTRIFICATION SYSTEM
ONE LINE DIAGRAM

Substation/tie station would be completely fenced for public safety at all locations. To protect electrical maintenance personnel, substation and tie breaker stations would be provided with 4/0 bare copper ground grid covered with crushed rock.

2.2 POWER SYSTEM PROTECTION

Appropriate protective relays such as phase, ground, differential, distance, and overvoltage devices would be applied to the power system to have adequate protection to the equipment and to provide safety for the general public in accordance with industry practice. Transformers would be equipped with winding temperature relays, sudden pressure relay, oil temperature relay, and oil pressure relays.

Surge arresters would be applied to the feeder breakers. The catenary system would be subjected to frequent low magnitude faults comparable to high vehicle load currents which are difficult to distinguish and detect by the overcurrent relays. High speed distance relay would provide primary and back-up protection. In order to accelerate fault isolation, transfer trip of remote circuit breaker would be provided. Feeder breakers (ac) would be equipped with auto reclosing protective devices which would reclose the circuit breaker after an interval of 15-30 seconds. In case of persistent fault, the circuit breaker would open on the second or third attempt. Catenary relays would override the magnetizing current inrush to on-board locomotive transformers.

Tie breaker station switchgear would be equipped with similar protective devices as indicated above.

2.3 OCS SYSTEM VOLTAGE RANGE

Traction electrification system would be based upon the following OCS voltage limits:

- Nominal OCS operating voltage: 25 kV;
- Maximum OCS voltage limit: 27.5 kV;
- Minimum operating voltage under normal system operation: 21.25 kV; and
- Minimum voltage limit under exceptional conditions: 20.0 kV.

However, the system should be able to function at voltages as low as 14 kV for 10 minutes and 12.5 kV for two minutes. These voltage limits would be confirmed and coordinated with the locomotive electrical data.

2.4 POWER FACTOR CORRECTION CAPACITOR & HARMONIC FREQUENCY FILTER

In the next study phase, requirements of the power factor correction capacitor and harmonic frequency filter would be determined by an analysis of the power system. This analysis would use the utility company power system data at the supply points and the locomotive motor characteristics.

2.5 TRACTION POWER RETURN CURRENT SYSTEM

Traction current is returned from the locomotives to the substations via running rails, ground wires, and ground. Impedance bonds would be installed to crossbond the four running rails. To minimize rail voltage rise, selected cross bonds should be grounded along the system right-of-way and connected to substation or tie breaker station ground grids. Substation/tie breaker grounding grids should be designed to have five ohms or less ground grid resistance to remote earth.

2.6 SIGNAL POWER SUPPLY SYSTEM

The signal power supply would be derived from the traction power system. This power supply would be subjected to frequent voltage variations, and therefore should be equipped with ac to dc and dc to ac converter system with complete protective devices. A back-up power supply system is required to assure continuity of signal power supply system.

2.7 SUPERVISORY CONTROL & DATA ACQUISITION SYSTEM (SCADA)

Computer based SCADA system would be used for monitoring and control of the unmanned traction power substations and tie breaker stations. At a minimum, the following signal points would be provided:

- Remote control of all circuit switchers, circuit breakers, and motor operated disconnect switches;
- Status indication of circuit switchers, circuit breakers, disconnect switches, and grounding switches;
- Status indication of protective relays, ac auxiliary power equipment, and dc auxiliary power equipment including the station battery and battery charger;
- Enable/disable automatic reclosing of feeder circuit breakers;
- Primary and secondary voltages, currents, and power factor;
- Maximum demand prediction;
- Circuit breaker tripping and low substation voltage alarms;
- Substation/tie breaker station switchgear housing intrusion and smoke/fire alarms; and
- Sequence of events recording to one second interval.

2.8 UTILITY METERING FACILITIES

The substation metering facilities would be decided in the next study phase. A nominal allowance for the cost associated with the equipment needed to accommodate the metering equipment was included in the capital cost estimate.

2.9 BASIS OF COST ESTIMATE

Figure 3 presents a schematic of Scott connected transformers connected to a three-phase, 115 kV, 60 Hz, PG&E supply at each traction power substation location. This type of transformer connection would reduce voltage unbalance and associated negative sequence currents in the PG&E supply system. For cost estimating purposes the following conditions were assumed:

- Five substations and four tie breaker stations were considered for the traction power distribution system. A group of two circuit breakers were assumed at the entrance of the underground tracks in San Francisco to isolate the OCS system in case of emergency. In addition, a group of two breakers were considered for the power supply to two CalTrain storage and maintenance yards. A total of 14 load interrupter switches would be used for electrification of the two yards;
- 115 kV primary supply voltage would be provided at each substation location;
- PG&E existing primary supply feeder tap to each substation would be within 1000 feet of the substation location, except at one substation which would require a one-mile, 115 kV, overhead line;
- Substation transformer connection to circuit switcher and circuit switcher to PG&E primary supply system and to secondary switchgear would be provided by exposed copper tubular bus; and
- Switchgear connection to OCS system would be provided by underground feeder cable system.

It should be noted that PG&E supply system configuration and short circuit infeed at each substation location would dictate the magnitude of harmonic distortion and voltage unbalance to the utility grid due to traction load. Transformer connections would improve the voltage unbalance and would not change the power factor or the harmonic distortion level. At this time, the requirement of such equipment to improve the power factor or to reduce the harmonic distortion level cannot be determined without PG&E input and system load flow analysis. However, a nominal cost was included in the capital cost estimate for such equipment. For preliminary engineering analysis of traction power substation requirements refer to Attachment 2.

2.10 OVERHEAD CONTACT SYSTEM

2.10.1 Types of Overhead Contact System

The three types of OCS -- simple catenary auto tension, simple catenary fixed termination, and single wire fixed termination -- are described below.

Type I - Simple Catenary Auto Tension Overhead Contact System (SCAT)

The basic mechanical requirements of the catenary system design are that no conductor be overheated beyond set temperature rise criteria. In addition, the electrical requirements need voltage drop in the OCS system under normal and abnormal

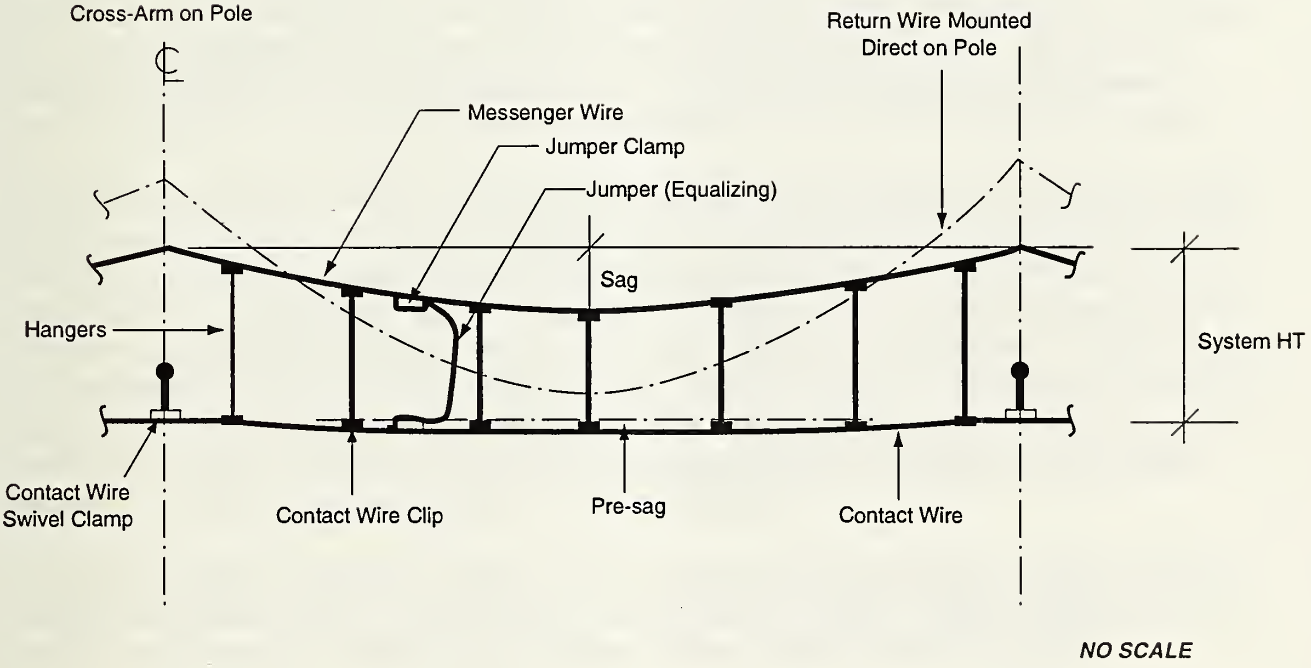


Figure 3
SIMPLE CATENARY CONFIGURATION

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operating conditions to be within specified allowable limits. With these constraints, a preliminary power system analysis was conducted to determine conductor wire sizes. The preliminary findings indicate that a 4/0 solid groove hard-drawn copper (Hd Cu) contact wire (CW) and a 350 kCMIL stranded Hd Cu messenger wire (MW) has adequate ampacity to sustain the operating power requirements of the vehicles.

An individual third wire for each track, called the return wire (RW), would be continuously strung on top of the pole and connected to running rails at appropriate locations, providing partial return path for the load currents. The return wire, which would also serve as a shield wire for lightning protection, would be 4/0 stranded aluminum conductor steel reinforced (ACSR). A simple catenary configuration is shown in Figure 3.

Both messenger and contact wires would be kept under constant tension by means of a counterweight system at both ends of a typical tension section about one mile long. Keeping the wires under constant tension eliminates practically all changes in sag as the temperature varies within the prescribed operating range. The contact wire is given a prescribed sag (pre-sag) of about 1/1000 times the span length (in accordance with industry practice) between the first and last hangers of each support span. The pre-sag remains practically the same throughout the entire range of operating temperatures, providing a smooth pantograph/contact wire operation and arc-free current collection.

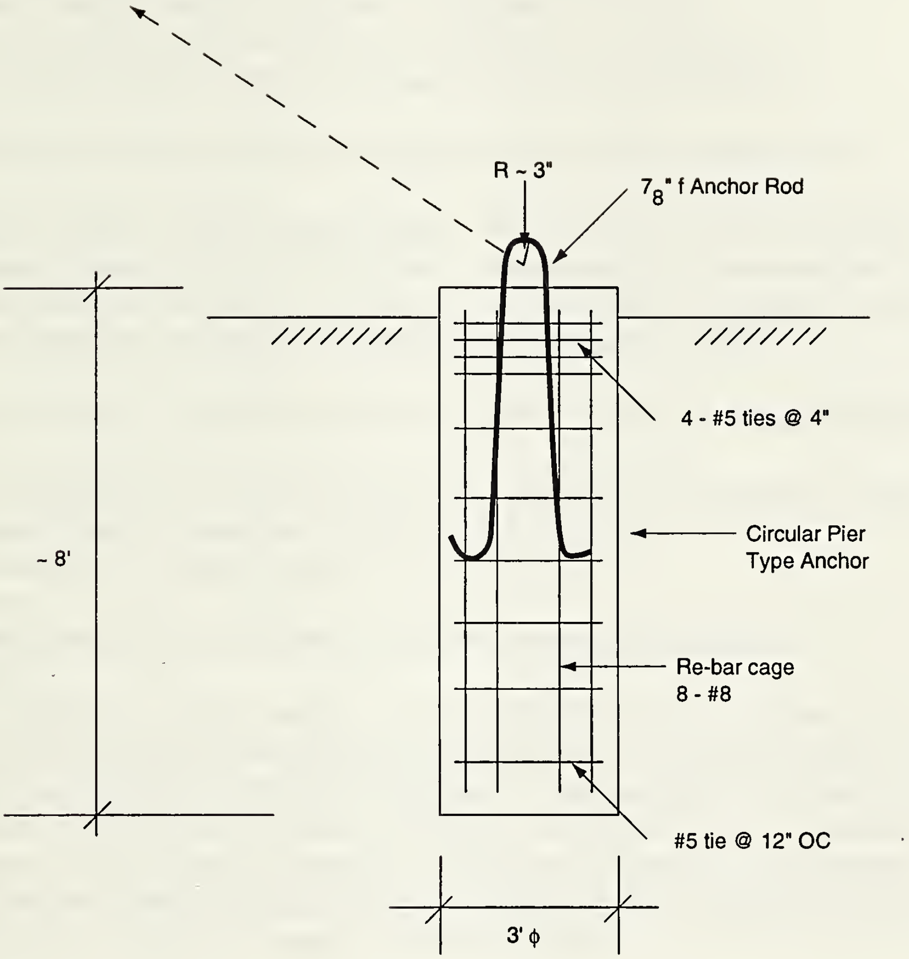
A midpoint structure would be located approximately in the middle of a tension section which would be fixed. The fixed midpoint would keep the counterweight system for the half tension sections to each side from collapsing and equalize the movements of the OCS supports (cantilevers) due to temperature changes. The cantilever support arms would be hinged and would be free to move and swing as the temperature rises and falls. This movement would be accomplished by the counterweights which are free to move up and down within the expected temperature range. Down guy anchors would be used to terminate catenary mechanical loads for every counterweight assembly and midpoint anchor. A typical down guy anchor is shown in Figure 4.

Equalizing jumpers would be used to provide suitable current division between the messenger and contact wires at every two to three spans. Flexible copper conductors of the same current-carrying capacity as the contact wires would be used for jumpers.

The contact wire would be staggered from side-to-side of the centerline of the track in order to evenly distribute wear of the pantograph carbon collector strips.

The cost estimate for the SCAT system was based on the following assumptions:

- All OCS structures would be located at the side of the tracks (center poles are not feasible due to limited existing center to center track clearance of less than 18.0 feet minimum required by code GO26D);
- The average SCAT span would be 175 feet (30 poles/mile);



Multi-Track OCS
3 Track Shown (Typical)

NO SCALE (700 UNITS)

Figure 4

TYPICAL DOWN GUY ANCHOR

- The average tension section would be 5,000 feet and the average midpoint would be 2,500 feet;
- Equalizing jumpers would be located every two to three spans;
- Pole grounding would occur every fifth pole (1,000 feet);
- Catenary hangers would be spaced a maximum of 30 feet;
- Return wire grounding would be every 20th span (4,000 feet); and
- Cross bonding of the right-of-way would occur every 2000 feet.

Type II - The Simple Catenary Fixed Termination Overhead Contact System (SCFT)

This system is similar to the simple catenary auto tension system as described above. The difference is that SCFT does not need counterweights to automatically adjust the sag in the system due to temperature variations. It also does not require the cantilever arms designed to swivel at the support to adjust for temperature effect.

The cost estimate for the SCFT system was based on the following assumptions:

- The vertical distance between the contact wire and the messenger wire, from which the contact wire is suspended, would be 1.5 feet; and
- The average pole spacing would be 100 feet.

Type III - Single Wire Fixed Termination Overhead Contact System (SWFT)

The system utilizes the same contact wire (4/0 Hd Cu) as the mainline, but tensions on the contact wire would rise and fall with temperature. The general type of support structure for the single contact wire is the headspan. The headspan is a two-wire system strung across several tracks attached on poles. The contact wire is suspended directly on the body span with no special hardware to cater for temperature movements. Occasionally single isolated poles supporting single or back-to-back cantilever are used at special tracks to provide contact wire supports and registration.

For the SWFT system, the average span is 100 feet, and the average number of wires suspended on the headspan is three contact wires.

2.10.2 Relationship of OCS Type and Category of Track

The selection of OCS type is influenced by the category of track for the Caltrain system extended to a Downtown San Francisco terminal. The categories are described below.

Category 1 - Mainline Tracks

Currently the maximum train speed on the existing system is in the order of 70 miles per hour (mph) or 79 mph maximum for FRA Class 4 track. It is envisioned that equivalent speed would be retained after electrification. A simple catenary auto tensioned with sagged contact wire is suitable for a wide range of train speed (25 mph to over 100 mph) to transfer electrical energy from the catenary to the pantograph. This type of overhead

contact system is in operation with train speed in excess of 100 mph on some European and Japanese electrified lines. Simplicity (inexpensive to maintain and operate) and efficiency (dynamic attributes) make it the consensual preference for most transit systems. A typical mainline OCS support is shown in Figure 5.

Category 2 - Tunnel Or Cut-and-Cover Subway Tracks

In the subway, where solar heating to the overhead contact wires is not a factor and the ambient temperature range is relatively low, a simple catenary fixed termination system would be used. The temperature variation in the overhead wire is minimal as the contact wire heating is mainly due to load current. As a result, the effect of sag in the system is lower. A fixed OCS could be used in the tunnel because trains would operate at low speed (10 mph minimum to 30 mph maximum). At this low speed, sagging and loss of tension in the contact wire translates to an inconsequential effect in the dynamics of the catenary. A fixed system in the tunnel also eliminates the need for providing extra supports and appurtenant equipment to accommodate the SCAT system in a limited space in the tunnel. A typical OCS support is shown in Figure 6.

Category 3 - Maintenance Yard Tracks

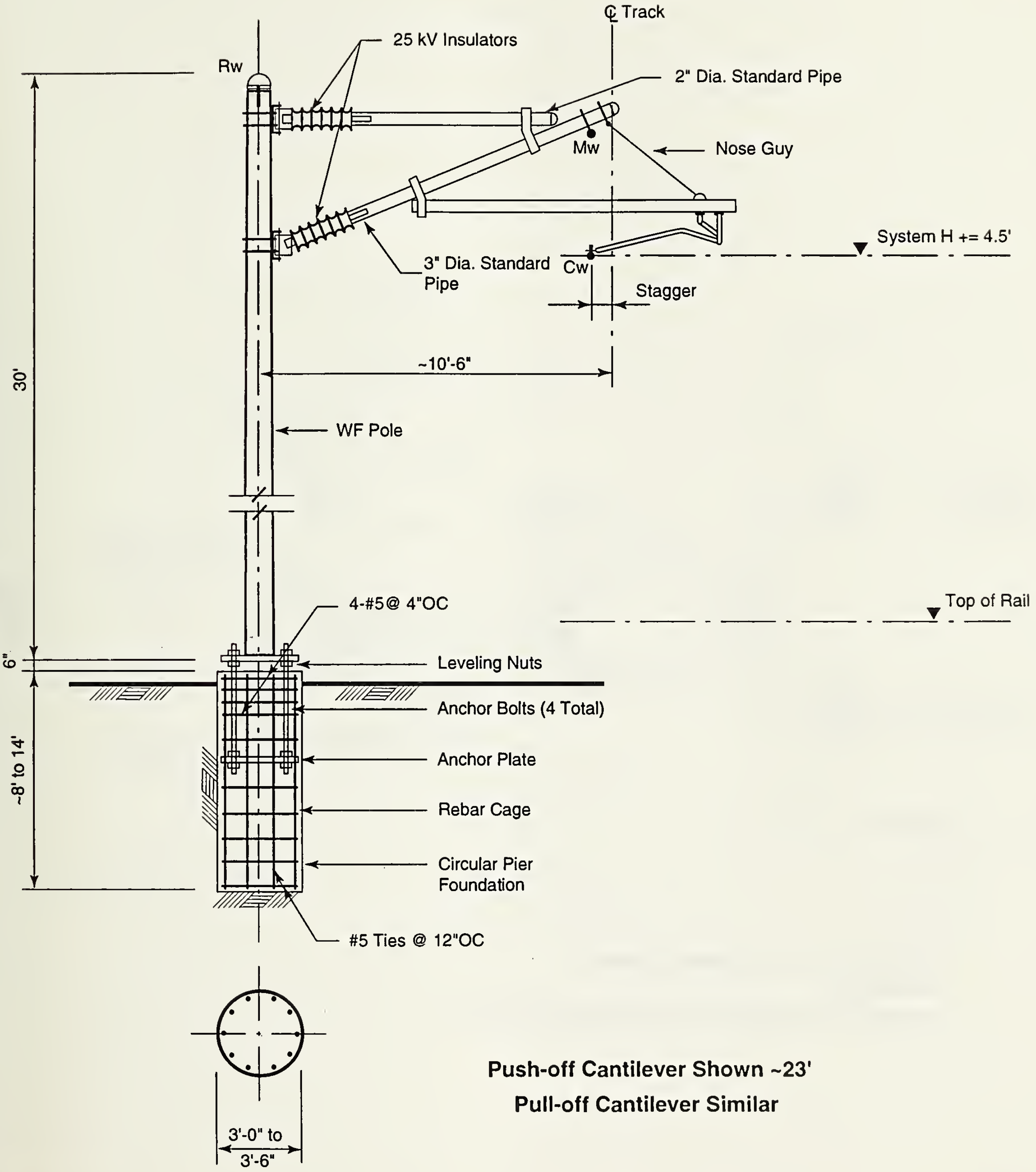
Single wire fixed termination system would be used for the maintenance yard where train speed is low and system dynamics is not constrained. A typical headspan OCS support is shown in Figure 7.

2.11 OCS SUPPORTING POLE STRUCTURES

Galvanized high strength wide flange (WF) poles fitted with a base plate would be used. These poles would be set in a poured-pier type foundations. Based on our preliminary design analyses using 13/psf wind on the WF pole and 8 psf on the catenary wires, the following pole sizes and their corresponding foundation depth and sizes would be required:

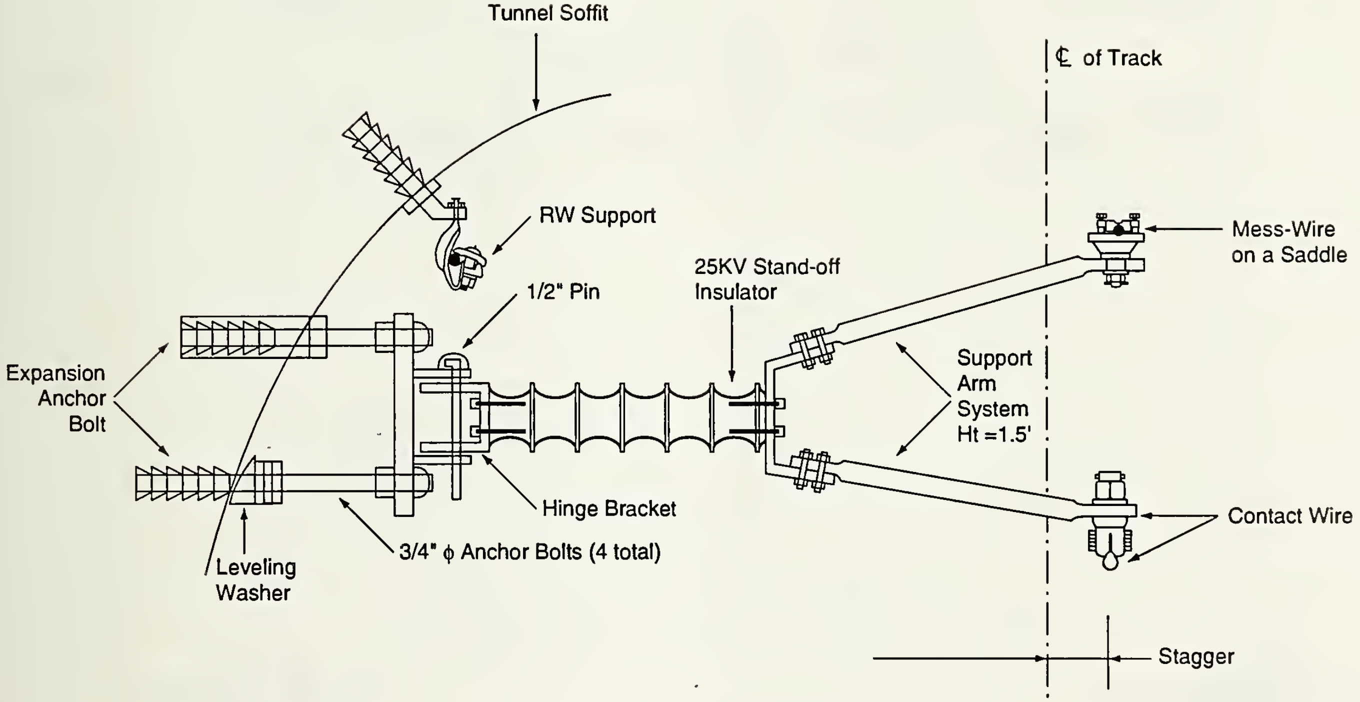
- Tangent/Standard Light Loading, using WF 8 x 31 lbs/ft poles having 3-foot diameter and 8-foot deep pier foundation;
- Light to Medium Curve/Medium Loading, using WF 10 x 39 lbs/ft poles having 3-foot diameter and 8-foot deep pier foundation;

  Medium to Heavy Curve/Heavy Loading, using WF 10 x 49 lbs/ft poles having 3-foot diameter and 12-foot deep pier foundation; and
- Counterweight (CWT) Pole/Extra Heavy Loading, using WF 12 x 53 lbs/ft pole having 3.5-foot diameter x 14-foot deep pier foundation.



Push-off Cantilever Shown ~23'
Pull-off Cantilever Similar

Figure 5
TYPICAL OCS SUPPORT AT MAINLINE
AVERAGE SPACING ~ 200'



Average Spacing - ~ 80 to 100 feet
No Scale
~ 250 units required for underground extension

Figure 6
TYPICAL OCS SUPPORT AT
CUT & COVER SECTION OR TUNNEL

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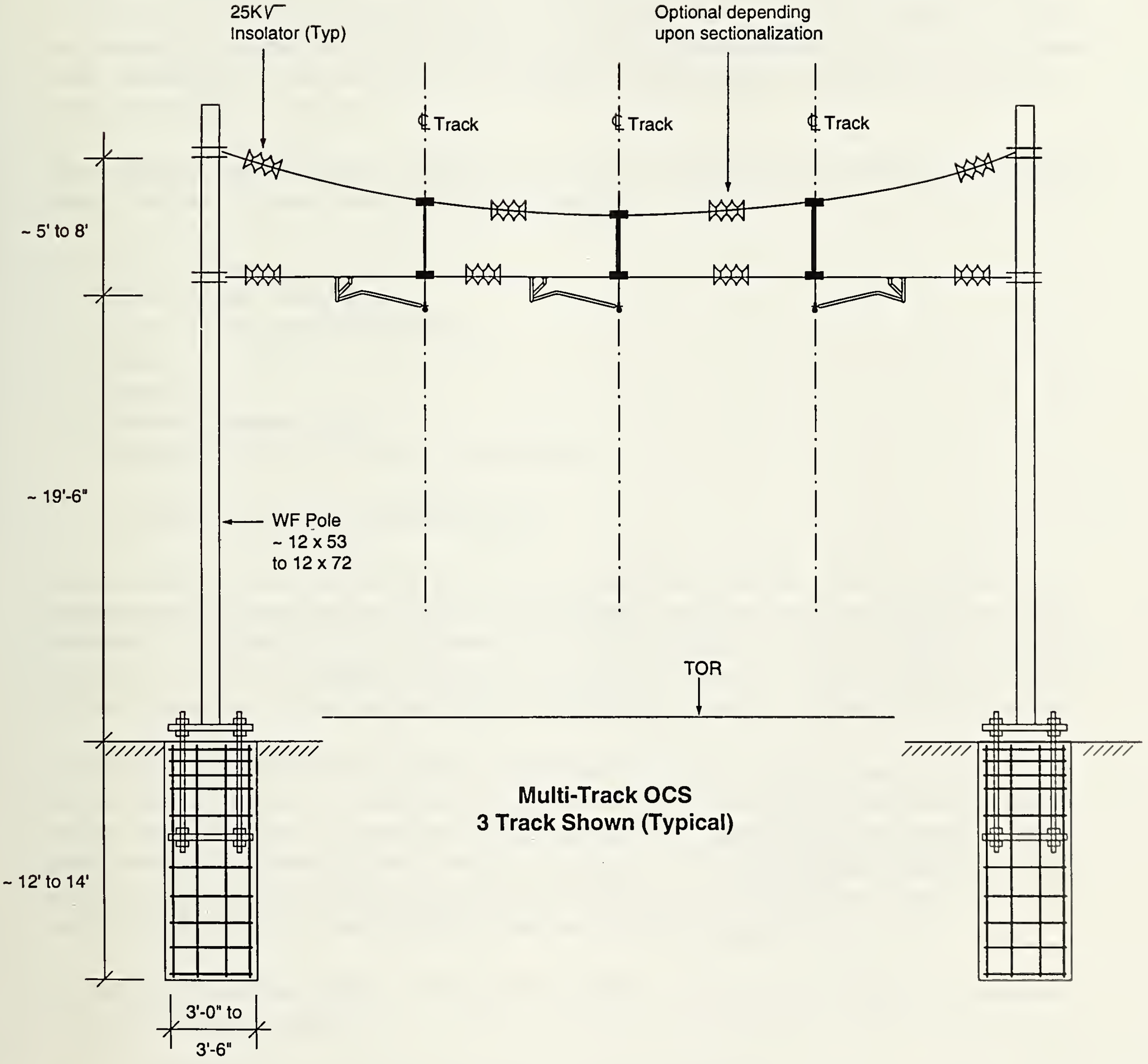

Figure 7
HEADSPAN OCS SUPPORT
MAINTENANCE YARD

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3.0 COMMUNICATIONS

Communication-related systems would be required for all electrification options involving the implementation of the DXT subway. The cost allocation for the subway communication system is $300,000. However, if full system electrification (25 kV AC) were implemented, communication system upgrades covering the entire CalTrain alignment would be required in conjunction with the signalling system improvements. The cost for system-wide communication improvements is estimated at $6.9 million, including $300,000 allocated for the DTX subway.

The following communication related systems were considered and estimated for the proposed CalTrain Downtown San Francisco station:

- Public Address
- Closed Circuit Television
- Fire and Emergency Management
- Radio
- Telephone
- Variable Message Signs
- Supervisory, Control and Data Acquisition

3.1 PUBLIC ADDRESS (PA) SYSTEM

The PA system would be used for emergency evacuation announcements as well as a supplemental communications system for emergency services, once the station has been evacuated. To qualify as such a system, all of the elements of the PA system would need to be supervised and an alarm given when a failure is detected. Such systems are listed by the Underwriters Labs and are further listed by the State of California Fire Marshall.

In addition to provisions for routine announcements from a central location (station control room), microphones would be located at entrances of the Downtown San Francisco station for use by fire and emergency response teams. Additionally, pre-recorded emergency evacuation announcements would be prepared. The pre-recorded announcements would be initiated by station supervisory personnel or, if a fire detector alarm remains unacknowledged for a predetermined time, automatically triggered.

To enable PA announcements to be understandable, architectural control of reverberation time would be required.

3.2 CLOSED CIRCUIT TELEVISION (CCTV) SYSTEM

The CCTV system is primarily a security aid. Coverage of ticket vending and change making machines, station entrances, escalator wells, and platforms are the usual areas covered. Views of ticket vending and change making machines are for revenue security. Views of escalator wells are to allow remote stopping of escalators for emergency

evacuation. Views of station entrances are for general security and verification of emergency evacuation. Views of the station platforms allow crowd control and aid operations in verifying train arrivals and departures. Fixed view cameras were assumed for this exercise. However, as the design is finalized, panning angle, tilt, and zoom may be considered if only one monitoring location were provided.

3.3 FIRE AND EMERGENCY MANAGEMENT (F&EM) SYSTEM

The F&EM system would need to be listed by the Underwriters Laboratory and the California Fire Marshall. Various smoke, combustion products, temperature and rate of rise of temperature detectors would be required as well as monitoring sprinkler systems. A "Fire Alarm Control Panel" which centralizes all alarms from detectors and sprinkler systems also would be required. Supplemental alarm panels may be required at entrances designated by the fire services.

In addition to fire detection, the F&EM system would contain intrusion detector capability to monitor doors to ancillary rooms, emergency exit doors and gates, and some form of entry authorization (card key) for various non-public areas in the station. The F&EM system contains the arrangement to incorporate "blue light" stations. These blue light stations allow emergency removal of power from the overhead power feed to the trainway. The fire services require these stations at each point where they may gain access to the trainway. They are generally located at ends of platforms (just off the platform) and at each end of special trackwork. The fire services may use rescue or special trains to take fire fighters to the location of a fire in the tunnel. Blue light stations are therefore required at each access point between tunnels.

3.4 RADIO SYSTEM

The tunnel would require radio coverage for train operations channels and other railroad functions. It is assumed that there would be a railroad police/security channel and a maintenance channel required. Additionally it is understood that within the near future all local public service radio would be converted to a trunked 800 MHz system. The BART communications people are planning to furnish two 800 MHz channels for the fire and local police. The same coverage should be furnished in the CalTrain tunnels. Additionally, the emergency services would require 800 MHz coverage in all areas of the station.

Because of the length of the tunnel, 800 MHz coverage is difficult, since the losses of the distributed coaxial cable antenna are considerable at these frequencies. A dual antenna system in each tunnel is recommended. One antenna would be used for transmitting to the mobile and portable in the tunnels(s) and the other antenna would be used to receive signals from the mobiles and portable. With this arrangement, one-way amplifiers can be used in each cable to make up for the losses at 800 MHz. The station proper would derive coverage by the use of a combination of leaky coaxial antennas running through

various ancillary rooms and space antennas to give coverage in the large volume areas such as the mezzanine and the platforms.

3.5 TELEPHONE SYSTEM

Three types of telephone service would need to be furnished by an electronic automatic (dial) telephone switchboard. Regular administrative dial telephone would be furnished in each of the areas where working personnel are normally stationed. Additionally, a telephone just inside the door of all ancillary rooms is recommended. This phone would be used to initiate a fire alarm as well as for normal administrative and maintenance functions. Additional maintenance telephones would be located next to equipment needing regular maintenance. Emergency telephones which connect directly to the control room when the handset is picked up would be used at various strategic locations. Each of the blue light stations and elevators would be equipped with an emergency telephone. Each emergency exit should have an emergency telephone just inside the door to the outside.

Additional direct connection phones used for passenger assistance would be located near the fare vending machines and at the platform level.

3.6 VARIABLE MESSAGE SIGN (VMS) SYSTEM

Recent ADA legislation has required the use of the VMS system to augment the PA system. These signs are required to closely repeat in text the spoken emergency messages on the PA system. The emergency evacuation messages would be automatically initiated when the PA messages are made. The VMS signs also would be used for routine announcements, such as train arrivals and departures, general announcements, such as time and date and pending fare or schedule changes, and commercial announcements.

3.7 SUPERVISORY, CONTROL, AND DATA ACQUISITION (SCADA) SYSTEM

An interface between the blue light stations and the SCADA system that controls the traction power to the tunnels and platforms would be needed. However, with modern control of station and tunnel ventilation by the use of programmable logic controllers (PLC), there is no need for a SCADA system to initiate control of the various station functions from the control room. The various functions can be directly remoted to the control room via hard wired data links.

4.0 SIGNALLING SYSTEM

In this study, the existing signalling system would be rehabilitated without upgrading the existing 40-year old equipment or upgrading the capabilities of the system to Central Traffic Control (CTC). Because of dual passenger and freight operation, the signalling system should be modified with additional upgrades that are not considered in the present cost estimate. The upgrades would be required to maintain schedules in emergency and maintenance situations.

To provide cost estimates for the signalling system, the CalTrain system was divided into two major sections and five segments as follows:

Section 1: San Francisco Downtown Extension

The San Francisco Downtown Extension includes new track work in Segment 1 (new Downtown San Francisco terminal to the Hooper Street crossover) and Segment 2 (proposed storage yard at 16th/Owens Streets in Mission Bay). Various signalling components considered in each segment are indicated below. The existing Caltrain CTC system would be modified to include segments 1 and 2. The modification was included in the capital cost estimate.

Segment 1

At a three-level underground terminal at Market/Beale in San Francisco, tracks for train control room in station structures, six special mounted signals, 10 switch machines, 14 track circuits, cabling system, interlocking logic, backup local control panel, and CTC equipment were considered. At the Hooper Street crossover, bungalows with miscellaneous signal components, two signal bridges, four signals, four switch machines, six track circuits, cabling system, interlocking logic, and CTC equipment were included. Between the station and Hooper Street, line cabling, including 27 conductors and #14 American wire gauge (AWG), between bungalows extending approximately 12,000 feet were considered.

Segment 2

At the proposed storage yard in Mission Bay, bungalows, six signal bridges, 14 signals, 10 switch machines, 22 track circuits, cabling, interlocking logic, and CTC equipment were considered.

Section 2: Electrification of Full CalTrain System

In order to be compatible with the electrification of the entire CalTrain system, the existing signal system would need to be modified. Modification to the existing signal system would extend from San Francisco to Gilroy and include Segment 3 (San Francisco to Pullman Way Yard), Segment 4 (Pullman Way Yard), and Segment 5 (Pullman Way

Yard to Gilroy). The work would be done at night or in a manner to permit continued operations. These modifications were included in the capital cost estimate.

4.1 SIGNAL SYSTEM ASSUMPTIONS

The following assumptions were made for the signal system as part of the upgrade of the CalTrain system to full electrification:

- The signal system would be made to be compatible with CalTrain system electrification rather than being upgraded;
- No special effort would be made to reduce the rail-to-ground resistance, as would normally be done for a new electrified system;
- The existing signal system block lengths would remain acceptable for the braking characteristics, speed, and operation of the electrified CalTrain system;
- Sufficient space would be available in the bungalows and for cases for the new track circuit equipment necessary to adapt the existing system to 100 Hz or phase shift overlay (PSO) II track circuits;
- An outside contractor would modify equipment, install cable, install signal bridges, and install cases in a timely manner; CalTrain would perform the final cutover and testing; and
- Rail would be continuously welded, except at special trackwork areas such as freight sidings or crossovers.

4.2 BASIS OF SIGNAL SYSTEM COST ESTIMATE

In determining signal system capital cost, the following assumptions were used:

- To the greatest degree practicable, the existing cases, logic, bungalows, and wayside signals would be used or re-used;
- Areas that now have overhead line wire would have the same functions transferred to underground line wire (typically new 27C #14), and areas that have no line wire due to the use of an electrocode system would have the electrocode modified to 100 Hz to transmit the same functions. These areas account for approximately 80 percent of Segment 3 and all of Segment 5;
- The upgrade of track circuits between signal locations would be to 100 Hz or PSO II type track circuits;
- Highway grade crossing logic that use audio frequency track circuits but no motion sensors or crossing predictors would not be disturbed. However, crossing cases that use predictors would need to be replaced with new cases (or racks for existing bungalows) with PSO track circuit and logic including battery and solid state gate crossing controller. In addition, there would be typically one additional new case per crossing to provide the PSO transmitter complete with power and battery. Per discussion with JPB personnel, it is noted that all grade crossing cases are either motion sensors or crossing predictor equipped;

- The Downtown San Francisco station and proposed storage yard at 16th/Owens in Mission Bay would be controlled from the San Jose CTC. Code would be transmitted via separate fibers in fiber optic cable installed from San Jose to San Francisco as part of communications upgrade to electrification;
- The traction power pole spacing from center of track would be adjusted to provide visibility for the existing signals up to 12.3 feet from center line of track (25 percent of the signal locations would need signal bridges);
- Rail would be made continuous for traction power negative return using dual 350-MCM web and impedance bonds and dual 250 MCM C bonds at standard joints for special trackwork;
- The estimate for Segment 3 was based on verbal descriptions of the trackwork and existing signal equipment from JPB technical personnel. The estimate for Segment 5 is based on Southern Pacific track signal charts plus verbal information; and
- Segment 4 (Pullman Way Yard) would have dc track circuits with a tower or remote control and have dwarf signals compatible with the electrification.

5.0 COST ESTIMATE

Capital cost estimates for CalTrain system electrification, including the costs associated with each subsystem of the electrification described in this report, are presented in a separate report issued by ICF Kaiser Engineers.

25kV AC
SYSTEM ELECTRIFICATION

Attachment 1

Pacific Gas and Electric Company
123 Mission Street
P.O. Box 770000
San Francisco, CA 94177
415/973-7000

May 21, 1996

Dev Paul
ICF Kaiser Engineers, Inc.
18800 Harrison Street
Oakland, CA 94612-3430

We have provided rough estimates to interconnect the proposed five CalTrain substations associated with the electrification project. The EDRO for the first substation is 2005. All interconnections are at 115kv. These rough estimates were based on the following:

Unit cost guides without the benefit of field visits.

Assuming overhead line construction is feasible at all locations, except in San Francisco, where all transmission line is underground.

Overhead line right-of-way costs are the same as line construction costs.

Assuming that system reinforcements are in place by 2005 so that interconnecting CalTrain loads do not cause network line overloads, or that mitigating network overloads are PG&E costs.

CalTrain will install their own substations.

Current PG&E E20T tariffs, which are subject to change.

Station 1: Refundable advance of $ 900,000.
Station 2-5: PG&E expense for connection.

Sincerely,

Chester Livingston

Chester Livingston
Corporate Account Representative
Business Account Services

bcc: Alan Saunders
Stan Nishioka
Efrain Ornelas

ICF KAISER
ENGINEERING & CONSTRUCTION GROUP

ICF Kaiser Engineers, Inc.
1800 Harrison Street
Oakland, CA 94612-3430
510/419-6000 Fax 510/419-5355

April 24, 1996

Subject: CalTrain Electrification Project
Minutes of the Meeting with PG&E

A second meeting took place at PG & E offices in San-Francisco-123 Mission street on Friday April 19, 1996 to continue our technical discussions on the subject project. List of attendees is shown in Attachment A.

The following items were discussed during the meeting:

1. PG & E indicated the negative impact of the single phase loads by the Caltrain Electrification Project to their transmission/distribution power supply system such as:

   a. Voltage unbalance and harmonic distortion

   b. Possible overheating of the generation equipment due to the negative sequence currents generated by the unbalanced phase voltages

   c. Concern of flicker caused by the fluctuating traction power load and its impact to the other customer's loads on the same power supply source

   The above negative effects to their system is not acceptable to PG&E. They prefer to supply three phase power instead of single phase power to each traction power substation.

2. PG & E requested ICF Kaiser to provide the traction power substation expected load demands i.e Average demand and Peak demand and the train operating schedule (See Attachment B). This data will be used by PG & E to perform preliminary analysis to determine initial net revenue from the project. This information will be used to compare with the company policy of the cost of investment to provide service to a customer. PG&E will provide a statement indicating any cost to the project that may be imposed now and/or in the future in order to meet expected demand load. This information will be provided to ICF Kaiser the week of 29th April, 1996.

   PG & E is willing to do a study to analyze the impact of the fluctuating traction power load to their system. This work effort would be to the project accounts.

3. The power factor at the PG & E metering point should be 85% lagging or better to avoid power factor charges.
4. Primary power supply voltage of 115 kV at each tentative substation location will be provided.
5. The preferred location of the San Francisco yard substation is near 22nd street. ICF Kaiser will mark tentative locations of the other substations on a set of drawings provided by PG & E. See Attachment C.

Prepared by: Dev Paul

Dev Paul/ Rey R. Belardo

P:\65928\PGE3

ATTACHMENT A

4/19/96

List of Attendees

G&E, Repr's

Name	Organization	Tel. No.
RR Belardo	ICF KE	510-419-6760
Robert Jenkins	PG&E Transmission Plng	415-973-7649
Fulin Zhuang	PG&E Transmission Planning	415-973-0502
Chester Livingsh	PGE Business Accounts	415 973 4830
ALAN SAUNDERS	" "	415 973 8413
EFRAIN ORNELAS	" SERVICE PLANNING	415 972-5617
JIAN NISHIOKA	" Transmission Planning	415-973-7614
DEV PAUL	ICF KE	(510) 419-6448

ATTACHMENT B

CALTRAIN ELECTRIFICATION PROJECT
TYPICAL TRACTION POWER SUBSTATION
POWER DEMAND

The typical values of average and maximum power demands at a particular traction power substation under normal and abnormal system operations are indicated below. These values correspond to peak hour train operation system as indicated in Table 1. The system is considered normal when all traction power substations are in operation and the system is considered abnormal when any one of the traction power substation is out of service.

1. **Normal System Operation**

   a) Instantaneous Power Demand (5 seconds)

      29.6 MVA

   b) Average Power demand (15 minutes)

      27.6 MVA

2. **Abnormal System Operation**

   a) Instantaneous Power Demand (5 seconds)

      39.1 MVA

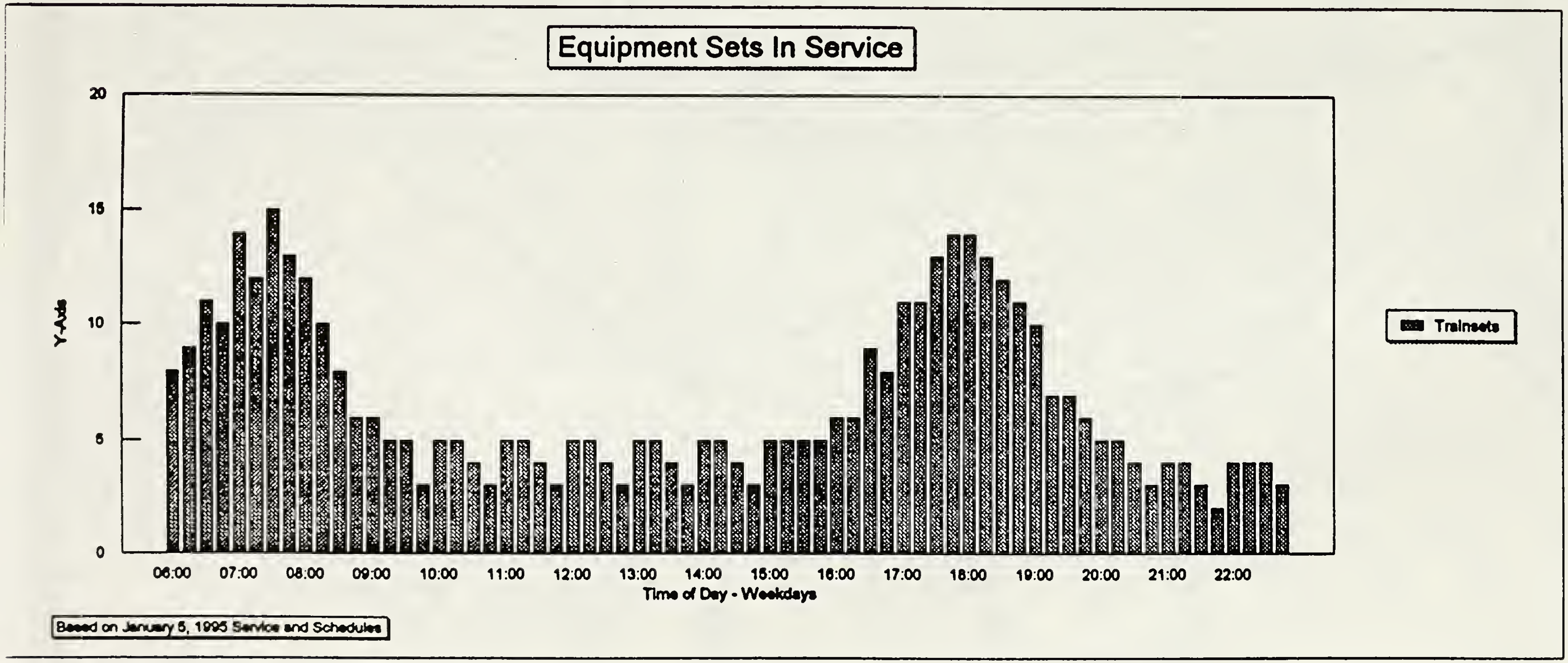
   b) Average Power demand (15 minutes)

      34.6 MVA

For the above power demands, we estimate the average power factor to be in the range of 85% lagging.

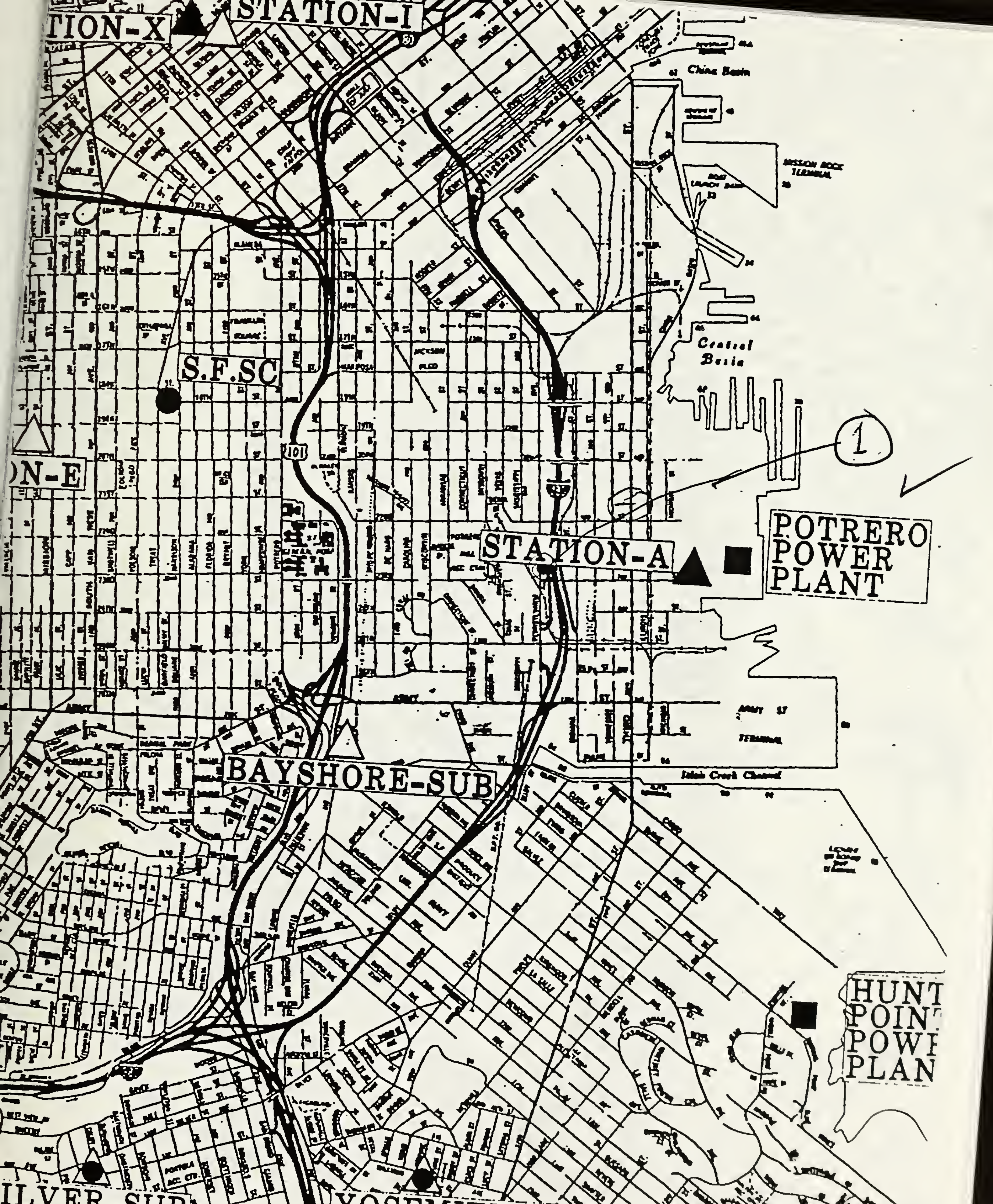
P:\65928\POWER

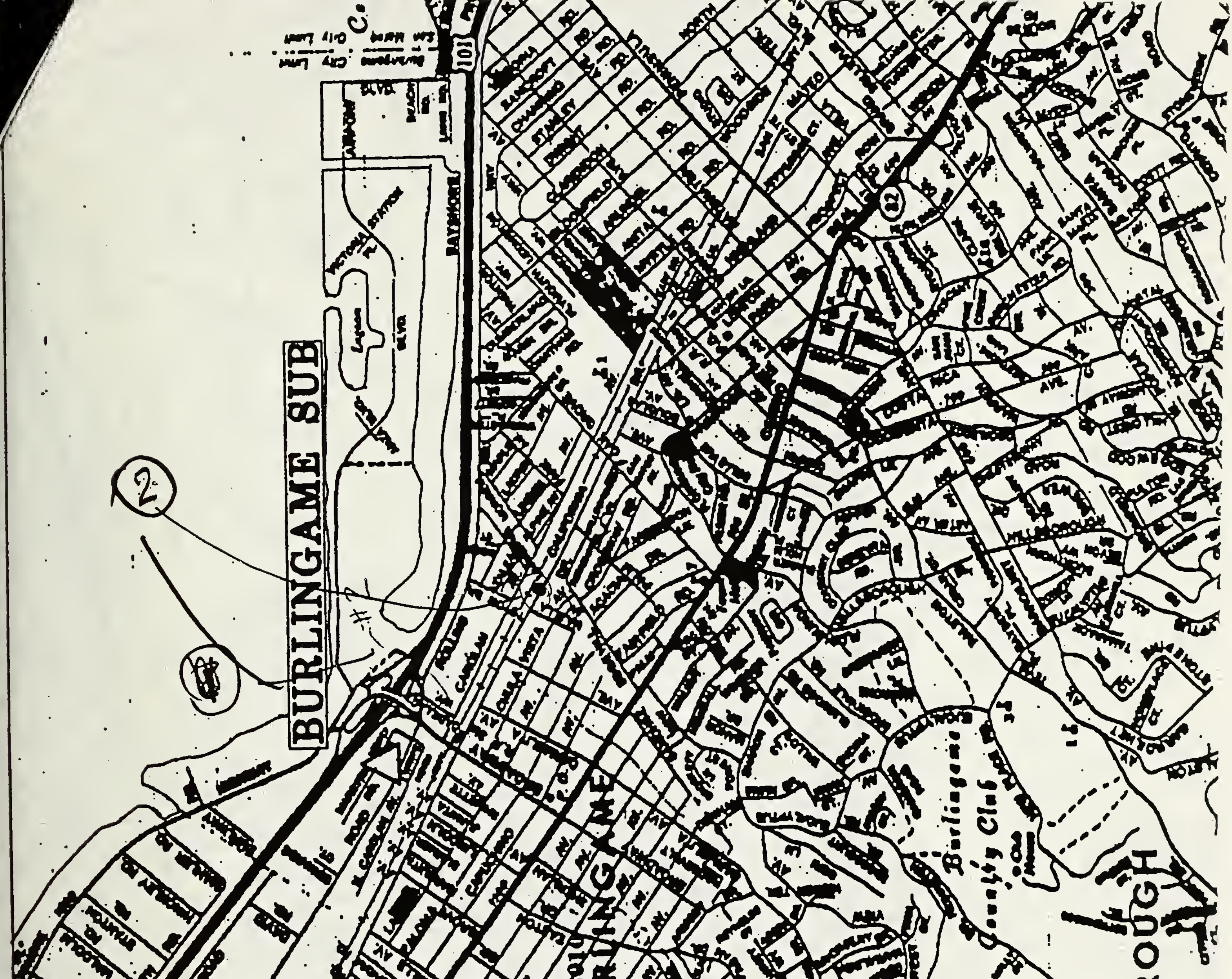
ATTACHMENT C



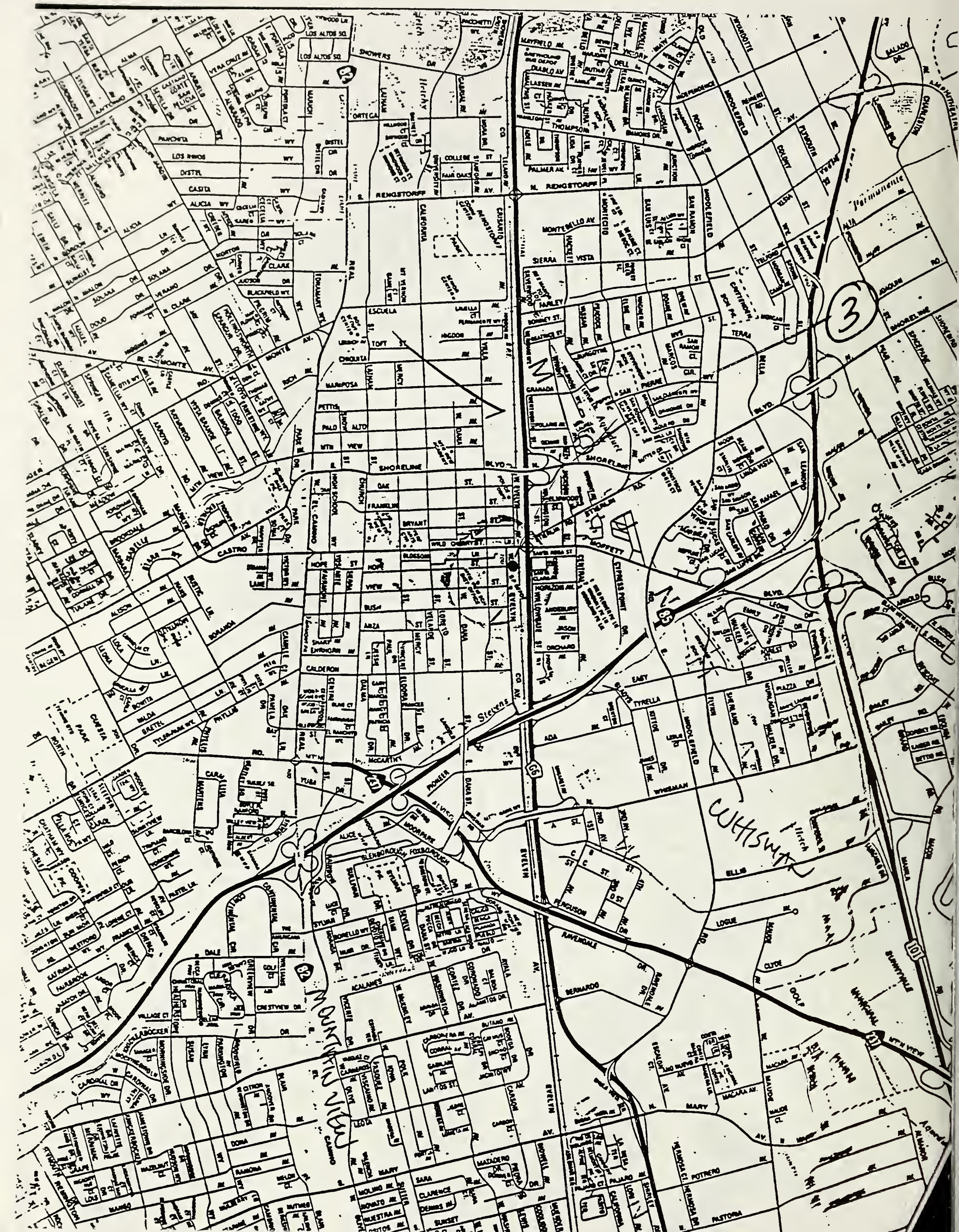
Based on January 5, 1995 Service and Schedules

TABLE: 1 TRAIN OPERATING SCHEDULE

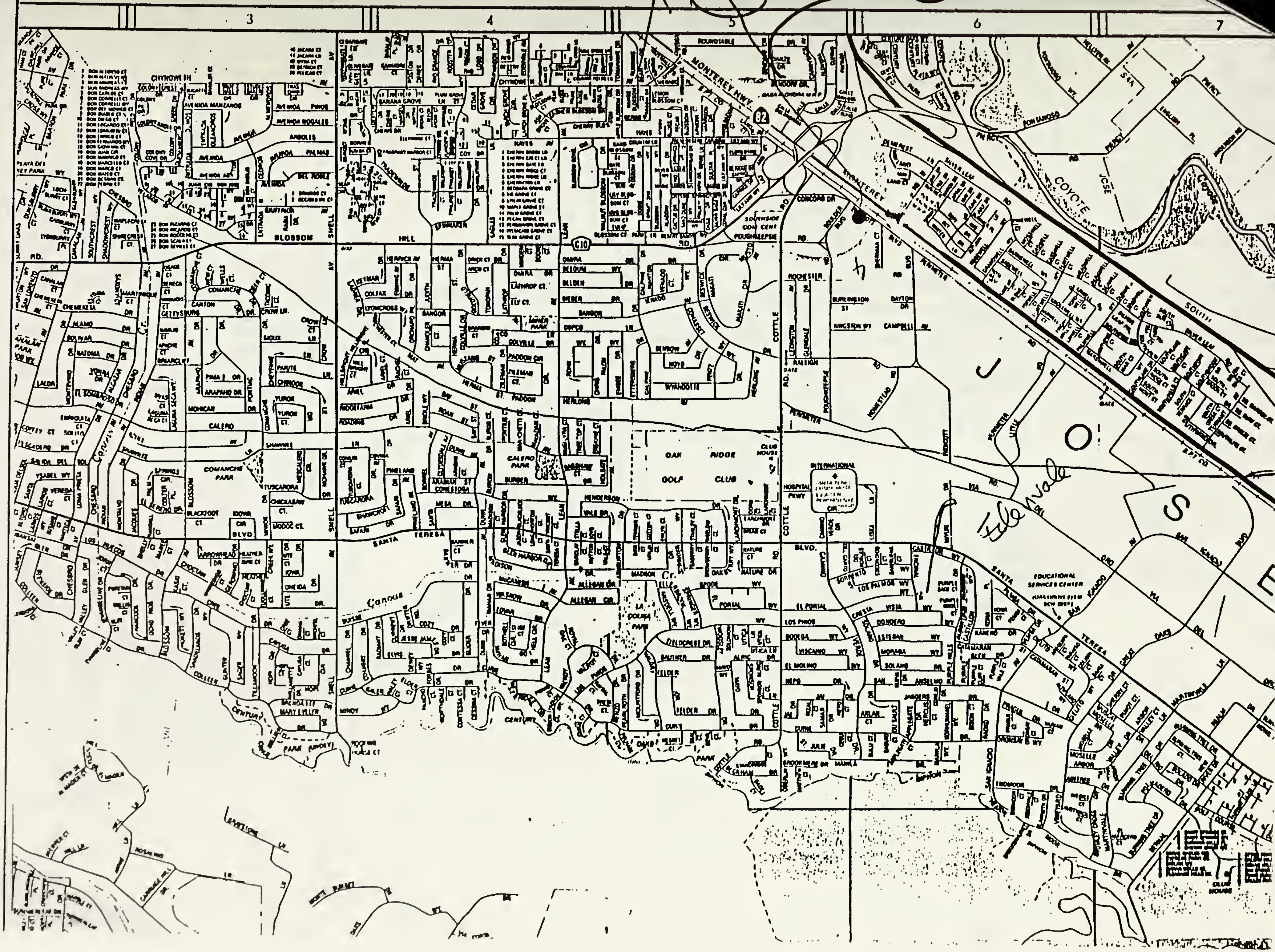

TION-X
STATION-I
China Basin
MISSION ROCK TERMINAL
Central Basin
S.F.SC
101
ON-E
1
STATION-A
POTRERO POWER PLANT
ARMY ST TERMINAL
BAYSHORE-SUB
Islais Creek Channel
HUNT POIN POWI PLAN
ILVER-SUB
YOSEMITE-SUB

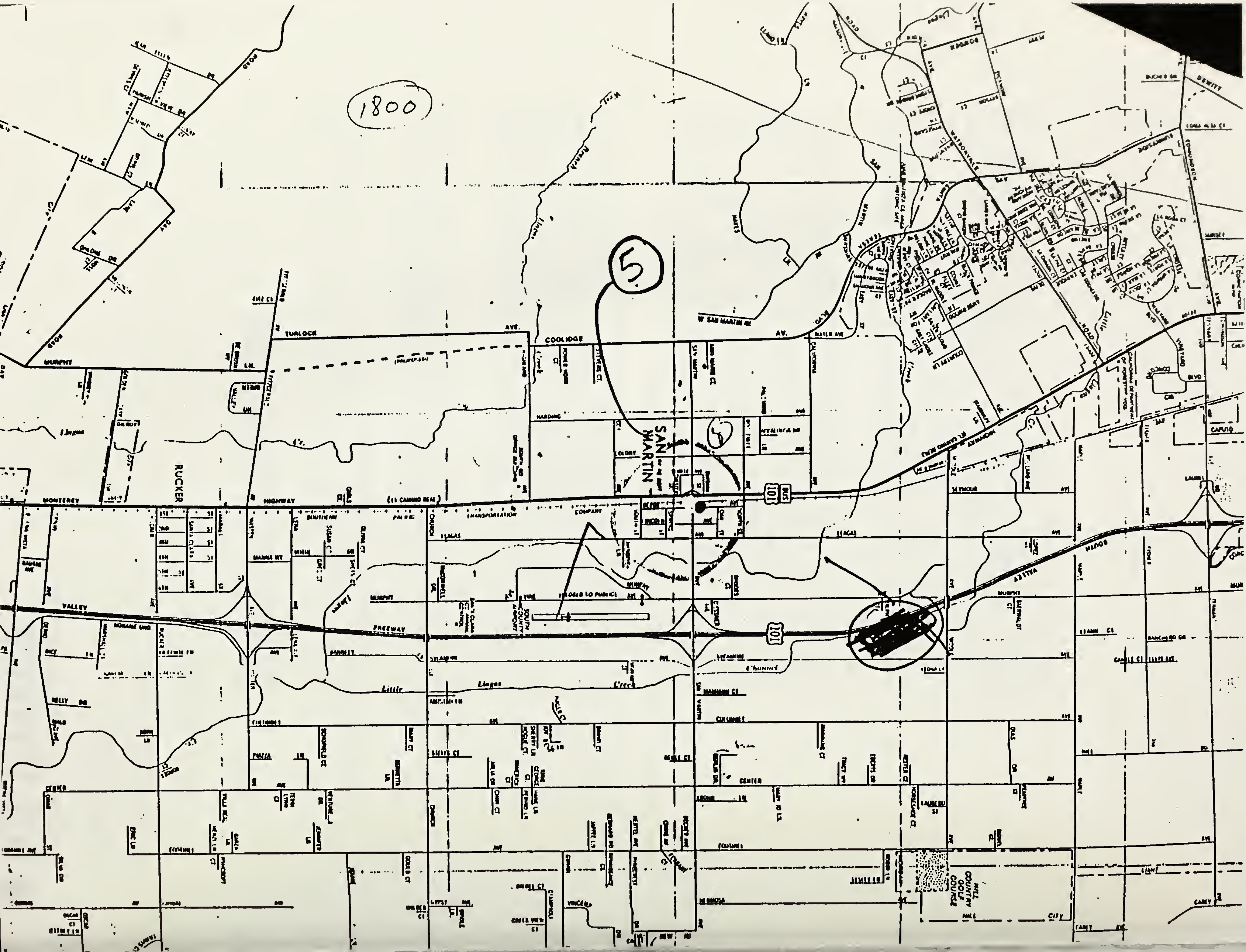


PT.B
BURLINGAME SUB
②
BURLINGAME
Burlingame Country Club
HILLSBOROUGH
101
82
RIDGE


MOUNTAIN VIEW
WHISMAN
3
SHORELINE BLVD.
EVELYN
W. EVELYN
CASTRO
EL CAMINO
REAL
N. RENGSTORFF AV.
CALIFORNIA
MIDDLEFIELD
MOFFETT BLVD.
CENTRAL
STEVENS CREEK
MTN. VIEW
ALVISO
MOORPARK
PIONEER
DANA ST.
LOGUE
ELLIS
FERGUSON
RAVENDALE
BERNARDO
CLYDE
DANA
CHURCH
HIGH SCHOOL
MERCY
CALDERON
VIEW
BRYANT
FRANKLIN
OAK
LATHAM
ESCUELA
SIERRA VISTA
MONTECITO
SAN RAMON
COLONY
PLYMOUTH
INDEPENDENCE
THOMPSON
SHOWERS
LOS ALTOS SQ.
ORTEGA
DISTEL
LOS NINOS
CASITA
ALICIA WY
CLARK
SOLANA
LEONG
BUSH
TERRA BELLA
FARLEY
CRISANTO
PASTORIA
MARY
AV.
101
237
82
85
ALVISO

UATION OF STREETS SEE CENTRAL SAN JOSE CITY MAP




1800
5
SAN MARTIN
RUCKER
MONTEREY
HIGHWAY
(EL CAMINO REAL)
101
BUS
FREEWAY
VALLEY
SOUTH VALLEY
TURLOCK
AVE.
COOLIDGE
AV.
MURPHY
HARDING
TRANSPORTATION
COMPANY
LLAGAS
SOUTH COUNTY AIRPORT
(CLOSED TO PUBLIC)
SANTA CLARA COUNTY ANIMAL CONTROL
Little Llagas Creek
W SAN MARTIN AV
WATSONVILLE
CENTER
CHURCH
SEYMOUR
CALIFORNIA
HILL COUNTRY GOLF COURSE
CAREY
DEWITT
ROAD
DAY
Llagas
Ranch
Creek

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ENGINEERING & CONSTRUCTION GROUP

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1800 Harrison Street
Oakland, CA 94612-3430
510/419-6000 Fax 510/419-5355

April 22,1996

Subject: CalTrain Electrification Project
Minutes of the Meeting with PG&E

A meeting took place at PG & E offices in San-Francisco - 123 Mission street on Monday April 15, 1996 at 3:00 P.M . List of attendees is included in Attachment A.

The purpose of the meeting was to discuss with PG & E representatives the proposed Caltrain Electrification project in relation to PG&E existing transmission and distribution power supply system.

Dev Paul and Rey Belardo of ICF Kaiser briefly described the CalTrain Project using the systemwide One line diagram for the traction electrification and substations location sketch (see Aattachments B and C). It was pointed to PG&E that we are assuming in the design concept of using 115 kV single phase primary power supply feeder taps from PG&E substation transmission line(s) to each Caltrain substation.

The following items were discussed during the meeting.

1. A table indicating the expected maximum peak hour power demand in MVA at each of the five (5) tentative substation locations was presented as shown in Attachment D. It was indicated that this demand represents the maximum expected train operation at peak hour period of operation. This demand will taper off during off peak hour period of operation due to lesser number of trains in the system.

2. Locomotive starting current v/s speed curves for LP-44 was given to PG&E (see Attachment E). This train starting current data will provide PG&E the information to check the impact of the instantaneous maximum load imposed on the power supply system. This will allow PG&E to determine if single phase or alternative three phase incoming primary power supply feeder circuit would be provided at each substation.

3. A drawing showing the substation location near 16th and Owens in the planned Yard area was shown and PG&E indicated that they may prefer to have this substation relocated near the 22th street to have a shorter underground conduit run to feed this substation from their existing power plant located at the 23rd street. ICF Kaiser indicated that the design criteria is flexible to accommodate moving the substation in the range of 4.0 miles in either direction. PG&E will indicate their preferred traction power substation locations in relation to their existing electrical facilities.

4. ICF Kaiser promised to provide a list of existing U.S. commuter rail transit properties that presently employ 25 kV single phase power supply for their electric locomotive propulsion system. See Attachment F.

5. PG&E's substation group indicated that their first preliminary look at the five tentative substation locations reveals that they have 115 kV power supply source available, however, they need to check and verify among their other engineering groups the feasibility of powering up the single phase loads with phase break between traction power substations.

6. ICF Kaiser is focusing on the need to develop an order of magnitude cost for the electrification system and requested PG&E to provide the following information:

   a) Primary power supply feeder system voltage level
   b) Power factor requirement
   c) Generated harmonic level limitation
   e) Any additional cost that PG&E may impose to the project to cover facility modifications, overhead or underground feeder etc to meet the required power demand at each substation location.

PG&E indicated that it would take at least three to four weeks to provide the required information. They need time to study the effect of single phase loads to their power system.

Attachments:

A. Attendees list
B. One line diagram
C. Substation location sketch
D. Substation MVA loading
E. Locomotive starting current v/s speed graph
F. Telephone list of the Transit properties that employ 25 kV single phase power distribution system
G. Technical papers

Prepared by: Dev Paul

Dev Paul/ Rey R. Belardo

P:\65928\PGE2

ATTACHMENT A

4/15/96

List of Attendees

Name	Organization	Tel. No.
RR Belando	ICF KE	(510) 419-6760
ALAN SAUNDERS	PG&E	415-973-8413
Stan Nishioka	PG+E	415-973-7614
Maylen Yue	PG&E	415-973-1381
Linda Trenholm	PG+E	415-973-1615
BOB MALAHOWSKI	PG&E - DSGN	415 973-9982
JOHN RANDOLPH	PG&E -- Subst. Engg	(415) 973-6787
Chester Livingston	PGE	415-973-4835
Dev Paul	ICF KE	510 419-644

ATTACHMENT B

ATTACHMENT C

ys/Holidays*

	249	251	253*	255	259	265	275	279	281
:23	8:53	9:53	10:53	11:53	1:53	3:53	5:53	7:53	9:53
:30	9:00	10:00	11:00	Noon	2:00	4:00	6:00	8:00	10:00
—	—	—	—	—	—	—	—	—	—
:36	9:06	10:06	11:06	12:06	2:05	4:06	6:06	8:06	10:06
:41	9:11	10:11	11:11	12:11	2:11	4:11	6:11	8:11	10:11
:45	9:15	10:15	11:15	12:15	2:15	4:15	6:15	8:15	10:15
:49	9:19	10:19	11:19	12:19	2:19	4:19	6:19	8:19	10:19
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:55	9:25	10:25	11:25	12:25	2:25	4:25	6:25	8:25	10:25
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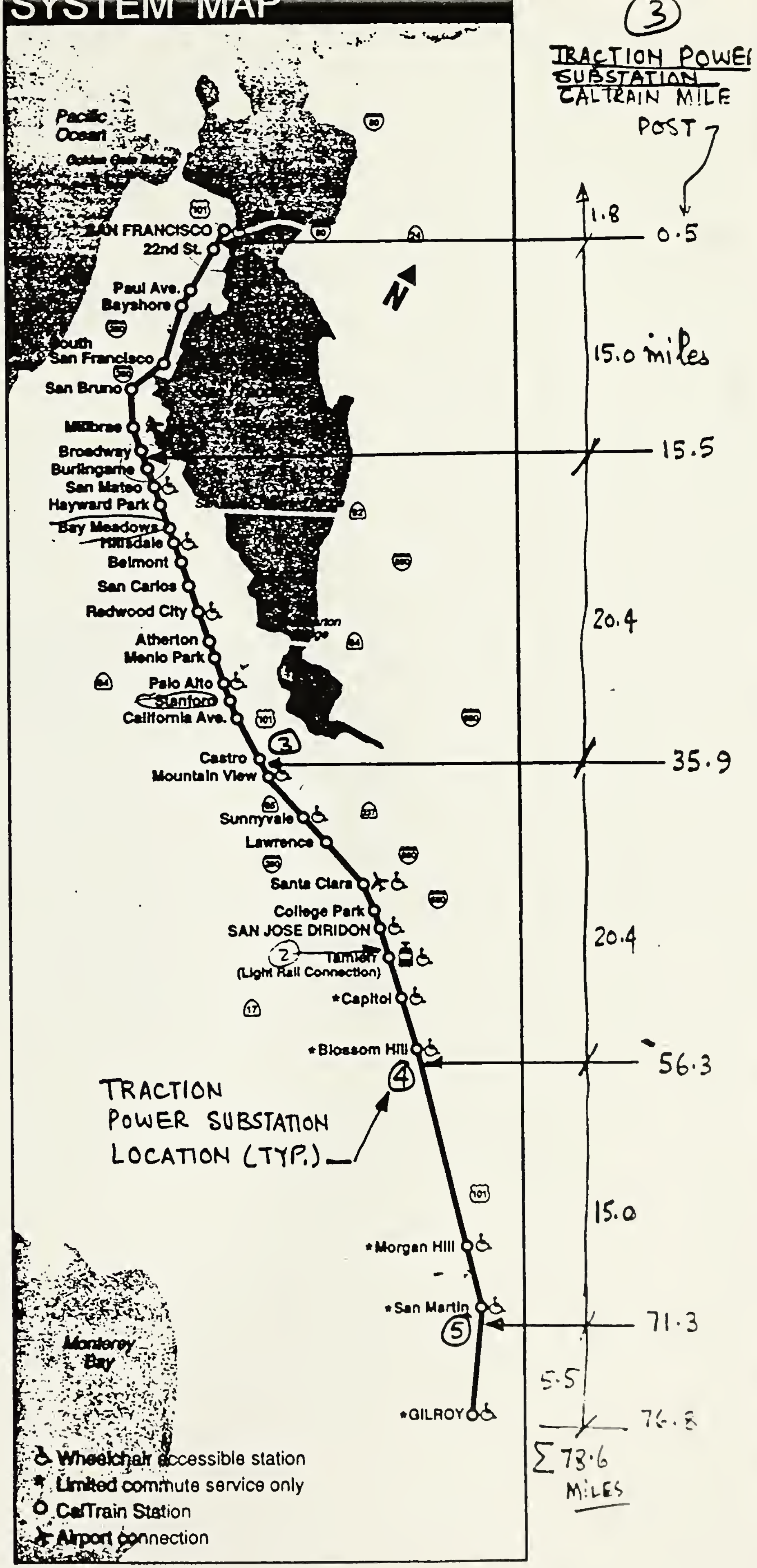
:58	9:28	10:28	11:28	12:28	2:28	4:28	6:28	8:28	10:28
:01	9:31	10:31	11:31	12:31	2:31	4:31	6:31	8:31	10:31
:03	9:33	10:33	11:33	12:33	2:33	4:33	6:33	8:33	10:33
:07	9:37	10:37	11:37	12:37	2:37	4:37	6:37	8:37	10:37
.11	9:41	10:41	11:41	12:41	2:41	4:41	6:41	8:41	10:41
:14	9:44	10.44	11:44	12.44	2:44	4:44	6:44	8:44	10:44
:17	9:47	10:47	11:47	12.47	2:47	4:47	6:47	8:47	10:47
•	•	•	•	•	•	•	•	•	•
:20	9:50	10:50	11:50	12:50	2:50	4:50	6:50	8:50	10:50
:22	9:52	10:52	11:52	12.52	2:52	4:52	6:52	8:52	10:52
:25	9:55	10:55	11:55	12:55	2:55	4:55	6:55	8:55	10:55
:27	9:57	10:57	11:57	12:57	2:57	4:57	6:57	8:57	10:57
:30	10:00	11:00	Noon	1:00	3:00	5:00	7:00	9:00	11:00
:34	10:04	11:04	12:04	1:04	3:04	5:04	7:04	9:04	11:04
:38	10:08	11:08	12:08	1:08	3:08	5:08	7:08	9:08	11:08
:43	10:13	11:13	12:13	1:13	3:13	5:13	7:13	9:13	11:13
:46	—	—	—	—	—	5:16	—	—	—
:49	10:18	11:18	12:18	1:18	3:18	5:19	7:18	9:18	11:18
:58	10:27	11:27	12:27	1:27	3:27	5:28	7:27	9:27	11:27

ndays/Holidays*

36	240	244	248	252	272	274	276	280
00	10:00	Noon	2:00	4.00	6:00	7:00	8:00	10:00
05	10:05	12:05	2:05	4:05	6:05	7:05	8:05	10:05
08	—	—	—	4:08	—	—	—	—
11	10:10	12:10	2:10	4 11	6.10	7:10	8:10	10:10
17	10:16	12:16	2:16	4:17	6.16	7:16	8:16	10:16
21	10:20	12:20	2 20	4 21	6:20	7:20	8:20	10:20
25	10:24	12 24	2:24	4 25	6 24	7:24	8:24	10:24
28	10:27	12 27	2.28	4:27	6:27	7:27	8.27	10:27
30	10:29	12:29	2:29	4.30	6:29	7:29	8:29	10:29
33	10.32	12.32	2:32	4.33	6:32	7.32	8:32	10:32
36	10.35	12:35	2:35	4.36	6:35	7:35	8:35	10 35
•	•	•	•	•	•	•	•	•
39	10.38	12:38	2 38	4.39	6:38	7:38	8:38	10:38
42	10 41	12 41	2 41	4 42	6:41	7:41	8:41	10:41
45	10:44	12 44	2.44	4 45	6 44	7:44	8.44	10:44
49	10:48	12 48	2 48	4 49	6.48	7:48	8.48	10:48
53	10:52	12:52	2.52	4.53	6 52	7:52	8:52	10:52
56	10:55	12:55	2.55	4:56	6:55	7:55	8 55	10:55
59	10.58	12:58	2.58	4 59	6.58	7.58	8.58	10:58
•	•	•	•	•	•	•	•	•
02	11:01	1 01	3 01	5.02	7:01	8:01	9:01	11:01
—	—	—	—	—	—	—	—	—
08	11:07	1:07	3 07	5:08	7 07	8 07	9:07	11:07
12	11.11	1.11	3 11	5 12	7 11	8 11	9 11	11.11
6	11:15	1:15	3 15	5 16	7 15	8:15	9 15	11:15
21	11.20	1 20	3 20	5 21	7 20	8 20	9 20	11:20
—	—	—	—	—	—	—	—	—
29	11:28	1:28	3.28	5 29	7 28	8.28	9:27	11:27
35	11:34	1 34	3 34	5 35	7.34	8:34	9:33	11:33



PRELIMINARY

SK-2

4/4/96

ATTACHMENT D

SUBSTATION LOADING IN MVA DURING PEAK HOUR TRAIN OPERATION SYSTEM

TPSS #	Normal		Abnormal	
	Present	Future	Present	Future
1	10.2	18.2	14.5	25.6
2	9.6	16.9	16.6	29.6
3	14.2	25.2	20.9	37.3
4	9.1	16.2	18	31.8
5	10.8	18.2	13.7	23

4-car, 7/11
5-car, 10/11

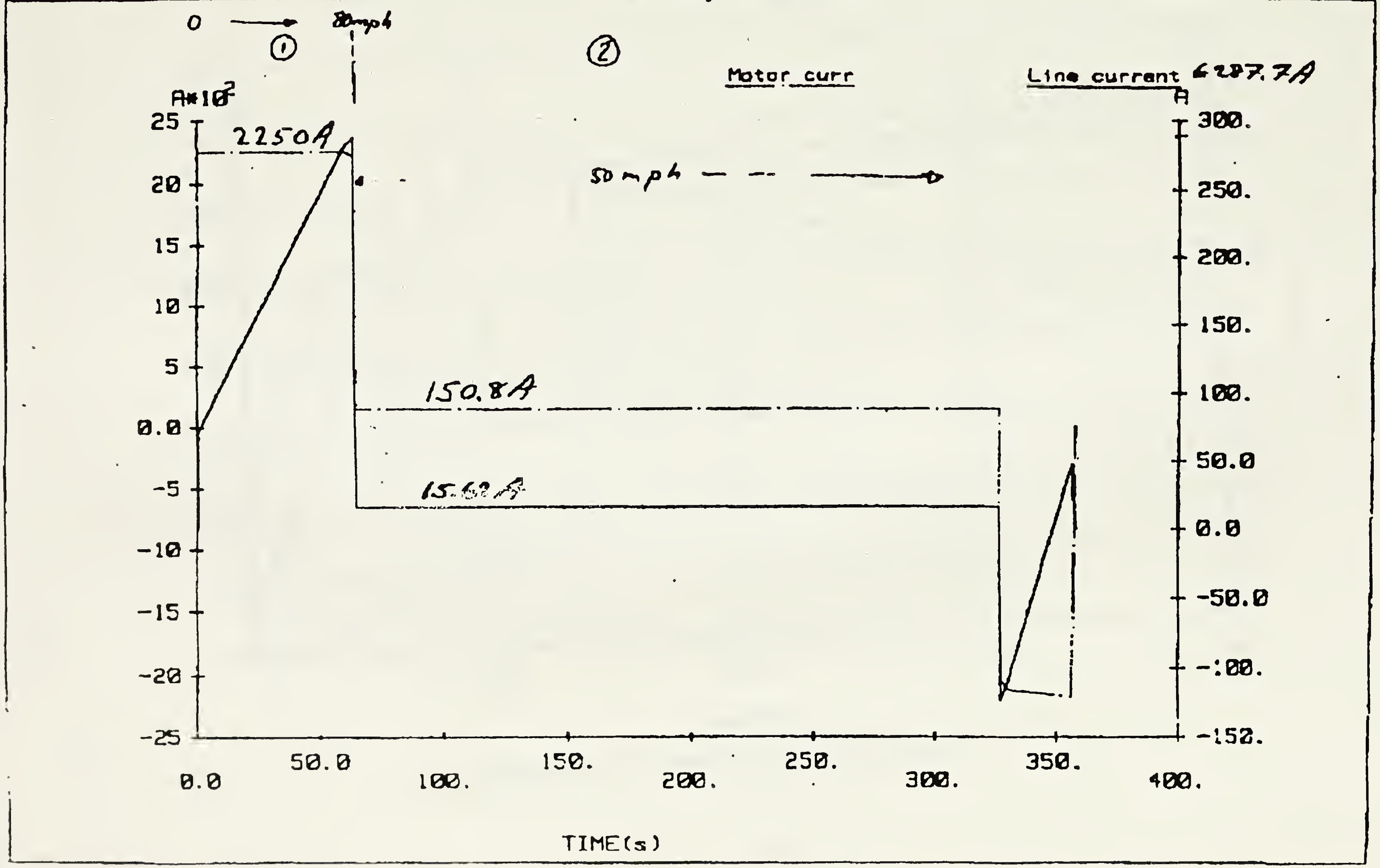
ATTACHMENT E

Appendix 1

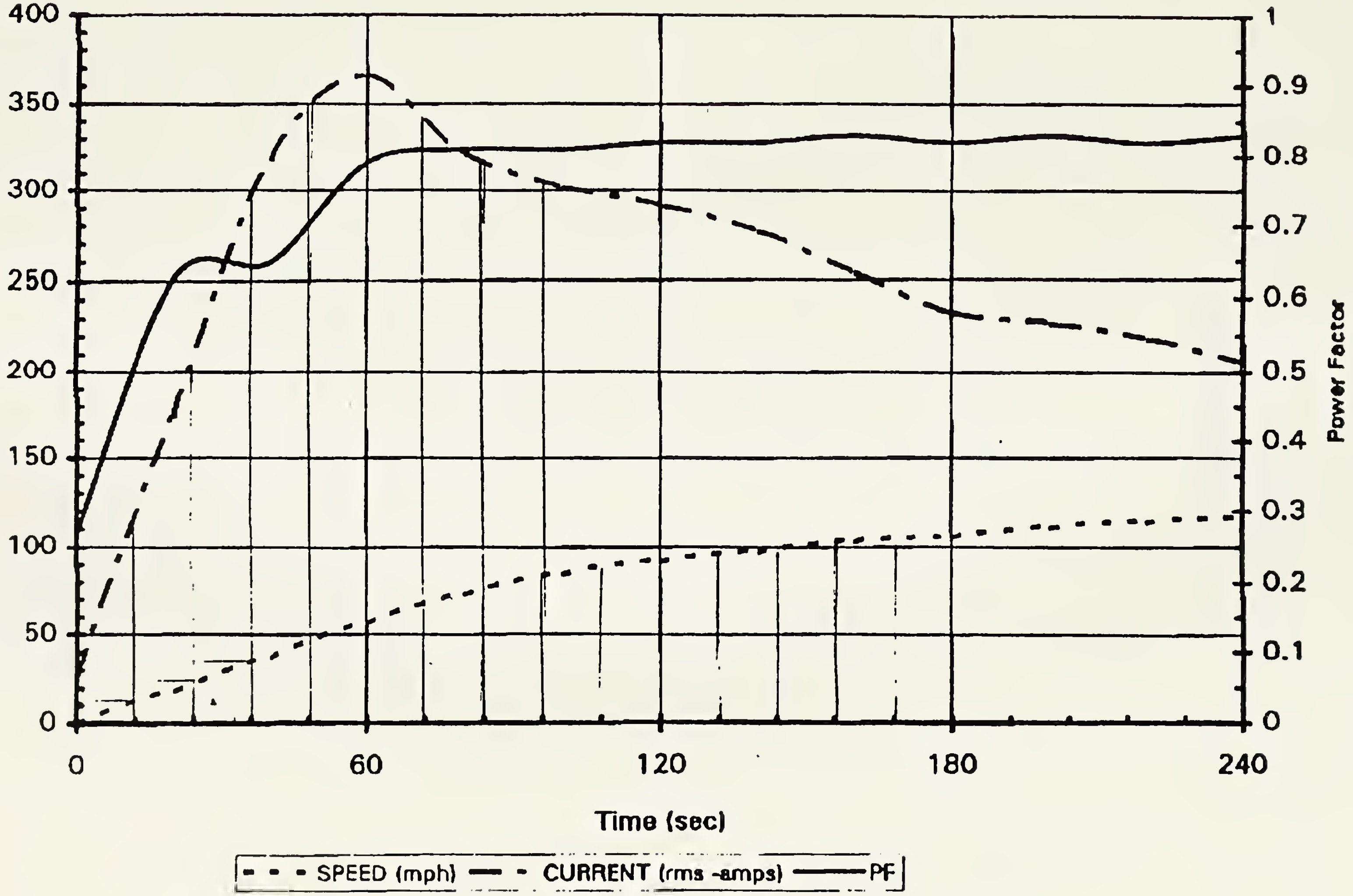
ABB TRACTION
TSPC 1.22c1

ALP44pl(turn) DD Mqt 1995-08-30-11.19
ALP44+10 cars, level track

Line voltage 25kV



AEM-7 Performance Data
25 kV/60 Hz, 8 car train



ATTACHMENT F

TELEPHONE LIST OF THE CONTACT PERSONS
TRANSIT PROPERTIES THAT USES 25 KV SINGLE PHASE POWER SUPPLY

1. Amtrak Transit

   Ken Watkins : (302) 429- 6371

2. NJT Transit

   Salvador Conte : (201) 491 - 8141

ATTACHMENT G

PUEBLO TRANSPORTATION TEST CENTER
ELECTRIFICATION PROJECT

by M. L. Long - Senior Member, IEEE
G. E. Griggs - Member, ASCE

International Engineering Company, Inc.

ABSTRACT

The electrification of the railroad test track in the U.S. Department of Transportation, Transportation Test Center in Pueblo, Colorado is a unique testing ground for electric traction. It is the first electrified 60 Hz system to be constructed in the U.S.A. for greater-than-100 mph service. This paper describes the design capabilities and testing of the power supply and overhead contact wire systems. Included are discussion of special features such as the one-mile test section for the testing of prototype overhead contact wire systems and the multi-voltage traction substation. The authors also give the results of some of the electrification - related testing performed by the DOT/FRA after implementation of the project.

INTRODUCTION

The Transportation Test Center (TTC) is situated on a 55-square-mile site close to Pueblo, Colorado, approximately 100 miles south of Denver. A brief description of the Test Center facilities pertinent to this discussion follows (see Figure 1).

- The Railroad Test Track (RTT) forms a closed loop 13.5 miles in length. It is a FRA Class-6 track designed for speeds up to 160 miles per hour, and allows for continuous high-speed running vehicles. It features 0°50' curves with 6-inch superelevation, with a maximum gradient of 1.4%.
- The Train Dynamics Track (TDT) is 2.2 miles long and is utilized for observing wheel/rail dynamics. It is a FRA Class-3 track and consists of a series of curves up to 5° and has a maximum operating speed of 80 miles per hour.
- The Facility for Accelerated Services Testing (FAST) forms a 4.8-mile loop overlapping a section of the TDT. It is FRA Class-3 track and consists of curves up to 5°. FAST is utilized for testing track and rail car components under accelerated wear conditions. The maximum operating speed is 80 miles per hour.
- The Balloon Track is a 1.6-mile loop used as a turnaround track for vehicles being tested on the RTT. It consists of 7°30' curves, with 5-inch superelevation. The maximum operating speed is 30 miles per hour.

The TTC offers comprehensive and controlled testing related to railroad and transit systems and operations. The Center is owned, operated, and administered by the U. S. Department of Transportation (DOT), and the Federal Railroad Administration (FRA).

The scope of this project called for the electrification of the RTT, the TDT/FAST, and the Balloon Track. In addition, a special Test Section was provided on the RTT to allow for easy replacement and testing of an alternate overhead contact system (OCS) and catenary configurations.

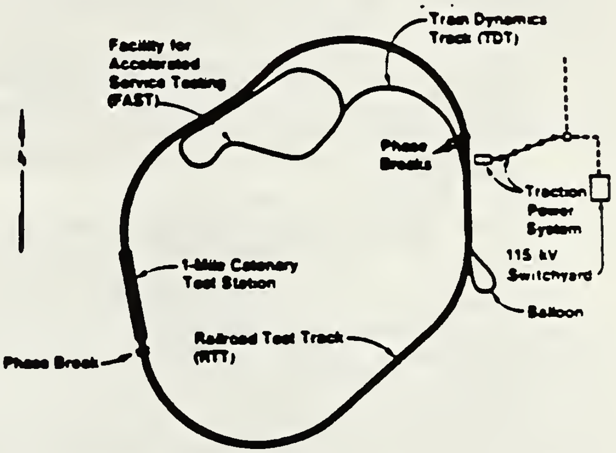

Train Dynamics Track (TDT)
Facility for Accelerated Service Testing (FAST)
Phase Breaks
Traction Power System
115 kV Switchyard
Balloon
1-Mile Catenary Test Station
Railroad Test Track (RTT)
Phase Break

Figure 1: Track Plan (Only Electrification Project Trackage Shown)

PROJECT DESCRIPTION

As illustrated in Figure 1, the electrification of the TTC includes the following:

- Modification to the existing 115-kV switchyard.
- Provision of a line tap at an existing 115-kV line and addition of one-half mile of 115-kV, single-circuit, three-phase, H-frame, wood-pole transmission line.
- Traction substation: 12.5/25/50-kV single phase ac.
- Overhead contact system (OCS) over the Railroad Test Track (RTT); high-speed compound catenary.
- OCS over the turnaround track (balloon); simple trolley
- OCS Test Section: One-mile long, located on the RTT.
- OCS over the Train Dynamics Track and Facility for Accelerated Testing (TDT/FAST); simple catenary.

The electrification of the RTT was completed and ready for testing at the end of 1979, the first locomotive running in early 1980. The electrification project was initiated to test equipment for the Northeast Corridor Improvement Project (NECIP) and for this reason the project was funded through the NECIP. Specific requirements were to test locomotives, pantographs, existing and proposed catenary, and specialized equipment - such as phase breaks

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(neutral sections) - to be used on the Corridor. Beyond those specific NECIP requirements, the Center was also intended to provide a facility flexible enough to accommodate generalized testing related to all electrification subsystems, such as vehicles, substations, overhead contact systems, signalling and communication, interference, operations, and maintenance.

CRITERIA

Design criteria were established to meet the stated objectives of the project and to reflect site specific conditions. The general design requirements were as follows:

- Multiple voltage 50/25/12.5 kV, adjustable to -35%.
- Single phase, 60 Hz.
- +10%, -15% allowable voltage variation at pantograph.
- 10,000 horsepower base load.
- Three NECIP overhead catenary system styles: 5, 3, and 1 fully insulated to 50 kV line-to-ground.
- Adjustable contact wire height from 15 feet to 24 feet above top of rail (ATR).
- Nine-foot, six-inch minimum clearance from centerline of track to face of pole.
- FRA track tolerances.
- AAR/AREA recommended electrical clearances.
- National Electric Safety Code (NESC) wind and ice loading.
- 55 mph maximum wind speed at which electric vehicles will operate.
- -30°F to +125°F ambient temperature range.

POWER SUPPLY

The Traction Power Substation is located adjacent to the RTT on the east side of the loop and is designed for single-phase operation, with a provision for future dual-phase. It is unattended and equipped with recording meters and other instrumentation for test monitoring.

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The substation is designed to provide three different secondary voltage levels at 50, 25, and 12.5-kV line-to-ground at 60 Hz. The traction transformer is rated at 16/21.3 MVA, OA/FA and is sized to accomodate a 10,000-hp continuous load or a 20,000-hp load for 15 minutes. The transformer is equipped with 4-12.5 kV secondary windings connecting either series, series/parallel or parallel to provide the three secondary voltage levels. Selection of voltage to the catenary is done by hookstick-operated air disconnect switches mounted vertically on a rack, which is enclosed by a fence for safety.

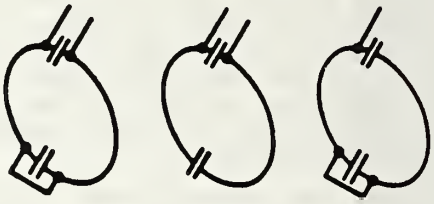
Based on the assumption that the voltage variations of the utility system are cyclic and predictable, the power transformer is equipped with a manually-operated, de-energized tap changer to provide +5% voltage in 2-2.5% steps to compensate for voltage fluctuations.

Another de-energized tap changer is provided in the secondary winding. This tap changer employs a regulating winding to buck or boost the secondary voltage without affecting the tertiary winding voltage. The taps are so arranged that +5% voltage is achieved in two 2.5% steps and -35% in 5% steps. This wide voltage range is designed to enable testing locomotive performance under simulated voltage drop conditions.

A 15-kV insulated ground return bus is located near the traction transformer, which is provided with current transformers to permit the measurement of ground/return currents. It is of interest to measure the division of traction current between substation ground mat and the rail-ground/return conductor paths. The insulated ground/return bus is connected to the rails by three, 15 kV class, 250 kcmil cables which allows for ungrounded operation of the traction substation, if desired.

The power supply is drawn from a line tap on an already existing 115-kV line. A new one-half-mile 115-kV, 60-Hz, 3-phase, single-circuit transmission line is designed to bring the power from this existing 115-kV line to the traction substation. The transmission line consists of three ASCR conductors, two shield wires, and two continuously buried counterpoise wires. H-frame wood poles with 8 disc insulator strings were used for supporting the lines. Each end of the circuit is terminated by means of a deadend-slack span arrangement. The power is carried from the traction substation to the overhead contact system on the RTT by means of aerial feeders.

There are adequate provisions in the design of the substation for projected future expansions. The HV system (115 kV) is designed to accomodate, with minimal disruption to service, another single-phase feed to a second traction transformer and a three-phase tap for a possible frequency converter station in the future.



50-kV System	Loop Feed	Simple Radial Feed	End Feed
Voltage Drop Baseload (%)	2.86	4.4	7.2
Allowable Overload, Giving Maximum 15% Voltage Drop (%)	104	76.9	44.5
25-kV System			
Voltage Drop Baseload (%)	7.2	14.9	Maximum load to maintain 15% voltage drop = 6,630 hp
Allowable Overload Giving Maximum 15% Voltage Drop (%)	25.2	0	-
12.5-kV System			
Maximum Load Maintain Maximum 15% Voltage Drop (hp)	6,220	3,660	2,088

Figure 2: Performance Parameters and Operating Configurations of RTT

The transformer, as previously mentioned, is designed to [redacted] hp for 15 [redacted] On the other hand, the maximum allowable load in the OCS is determined considering several factors. These factors include:

a) Voltage drop criteria of +10%, -15%,
b) continuous current rating of the OCS,
c) operating configuration of the RTT, i.e., loop, radial or end-feed,
d) OCS voltage level.

Section breaks are installed in the RTT, one close to the substation and another halfway around the loop. Disconnect switches are used to bridge these section breaks to obtain the different operating configurations, as shown in Fig. 2.

The impact of a large single-phase load applied to the utility network, particularly where the available short circuit level is low, is a major consideration. System studies and power measurements were made in order to establish criteria and policy for the acceptance of this load. From these studies the following policy was adopted with the two utilities (Southern Colorado Power Company and Public Service Company of Colorado, SCPC/PSCC) for the electrification power system:

a. Reactive Power. Only space need be provided in the traction substation for future power factor correction equipment. There are no limitations on reactive power; however, fluctuations in reactive power due to regenerative breaking may cause undesireable voltage fluctuations. If these fluctuations exceed the power company [redacted], then corrective equipment shall be installed.

b. AC Harmonic Currents. Space is provided for the future installation of harmonic filters and power factor compensation equipment, if initial system test indicates that they are necessary. Harmonic monitoring equipment was placed in the control room supply. The traction transformer is provided with a tertiary winding rated at 7.2 kV, 6.0/8.0 MVA OA/FA to connect this equipment.

c. Voltage Unbalance. The catenary load must not cause a voltage unbalance for: any continuous period of over 1% at the 115-kV critical bus; less than 15 minutes duration more than once an hour, up to 2% unbalance; and for more than once every two hours, up to 3% unbalance.

d. AC Regeneration. In view of the complex nature of ac regeneration, only some basic metering and relaying was installed at the traction substation as a first step to monitor, record and provide an adjustable level of regenerated energy flowing back into the supply system (adjustable reverse power relay). The exact course to be followed will depend on the findings of initial regeneration testing. Should results prove regeneration acceptable to the utility, additional relaying will be required where the DOT and utility network interface.

Since the magnitude of full-load current can almost equal the fault current for a fault at the far-end, discrimination between fault and full-load current is required. For this reason an angle impedance relay is provided as a blinder to a mho distance relay. In addition to these relays, the overhead system is provided with overcurrent and directional power relays. The traction transformer is provided with a standard set of protective relays to include differential, pressure and thermal relays.

A majority of the meters are strip-chart recording meters, which obtain a complete record of test results. The possibility of metering regenerative power is also available with zero-centered meters.

The control panels, auxiliaries, and other devices are housed in a control equipment enclosure. The enclosure is equipped with heating and air-conditioning to protect instruments and devices from temperature extremes, to maintain battery efficiency and to provide a suitable environment for test personnel during extreme weather conditions.

OVERHEAD CONTACT SYSTEM

Railroad Test Track (RTT)

The RTT is electrified, using a compound catenary, referred to as Style 5 (Figure 3 and 4) which was initially proposed for installation on the new section of the NECIP from New Haven to Boston. Since the RTT is designed for 160-mph operation, it allows testing of the catenary for speeds envisaged on the Corridor. A constant-tensioned, counterweighted system supported from single-track cantilever structures is provided.

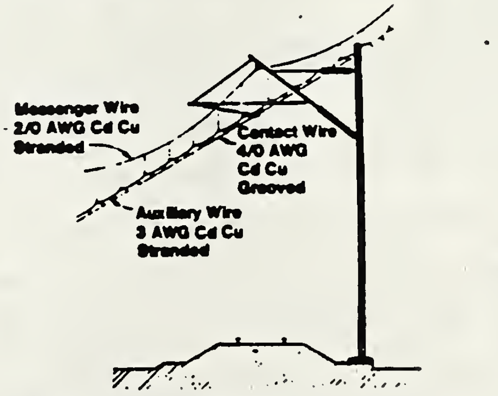


Figure 3: Compound Catenary (Style 5) for Railroad Test Track (RTT)

The Style 5 compound catenary consists of a [redacted] contact wire. All [redacted]. Maximum staggers of 8 inches on tangent and 10 inches on curves are used. Equalizing jumpers consisting of highly flexible 4/0 AWG copper-stranded conductors are provided in every other span and at overlaps. For safety and impedance considerations, a 2/0 AWG ASCR (Quail) return wire is provided and attached to the tops of the poles with direct connections to the rail every half-mile. The maximum span length between structures is 210 feet and tension section lengths are no longer than one mile. A 5-span overlap arrangement is used to accommodate the adjustable contact wire height. Cast iron counterweights are used with adjustable stops initially set at -10°F.

Standard support structures consist of augered rein-

Figure 4: RTT Support Structure and Crossarm

forced concrete foundations with bolted-base, ~~galvanized steel poles.~~ The standard support pole used is a 8W31 section. Crossarms are made of galvanized steel pipe, porcelain insulators, and malleable iron components. Crossarms are clamped to the pole in order to allow for variation of the contact wire height from 15 feet to 24 feet, ATR. Initial installation was set at 21'-6" ATR. Various types of support structures were required. For purposes of investigating alternate types of support poles, a half-mile section of pre-stressed concrete poles has been included. The concrete poles were direct-embedded and back compacted with soil; therefore they did not require a separate concrete foundation.

Two 25-kV phase breaks are incorporated in the catenary. This configuration allows the two catenary sections to be isolated for a future dual-voltage or two-phase system operation; both locations require special support structure configurations. Because high-speed 50-kV phase breaks were not available, a floating ground was provided between two 25-kV phase break sections for use at 50-kV. For NECIP testing purposes, German and British phase breaks were initially installed.

The phase break location nearest to the substation (see Figure 5) is considered to be a "phase break test facility" with additional conduits provided for the substation to allow for future instrumentation, loading resistors, etc., to test phase breaks up to 50 kV. Hook-operated disconnect switches and insulated supporting cross arms allow any installed phase break to be grounded or isolated as required.

A 2/0 AWG ACSR ground/return wire is provided for the overhead system. The conductor interconnects all structures (each to some extent self-grounding) and provides a continuous ground/return path for the return current in conjunction with the rails. The ground/return wire is connected to the rail approximately every one-half mile. Although desireable, more frequent rail grounding was not put in as the DOT/FRA plan to signal the tracks. Track switches are cross-bonded. Rail joint bonds are provided to maintain return traction current continuity in the jointed rail areas, approximately 20 percent of the RTT. All bond and ground connections to the rails were exothermic welds.

Figure 5: Phase Break Under Test

TDT/FAST Tracks

A simple catenary was designed for use on the TDT/-FAST (Style 5A-Figure 6) consisting of the same messenger and contact wire as for Style 5. The TDT/FAST has a maximum operating speed of 80 mph. A constant-tensioned system is used and supported from single-track cantilever structures. However, due to the sharp curves (up to 5 degrees) and lower class track (AAR Class 3) than the RTT, maximum span lengths are 180'. In other respects, the TDT/FAST overhead contact system is quite similar to that used on the RTT. Although designed at approximately the same time as the RTT, the construction of the TDT/FAST electrification has been postponed. It should be noted that the simple catenary equipment proposed for the TDT/FAST will most likely be the more common type of catenary to be used in future railroad electrification. For isolation purposes, 50-kV section breaks will be incorporated at the junctures between the TDT/FAST and RTT.

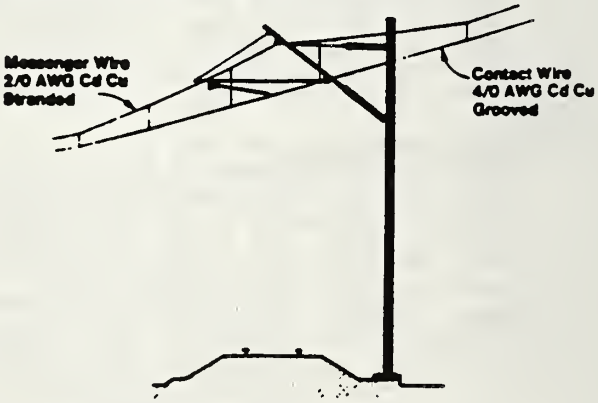


Figure 6: Simple Catenary (Style 5A) for the TDT/FAST

Balloon Track

Electrification of the Balloon Track was necessary in order to allow electric trains running on the RTT to turn around. Because the maximum train operating speed on the Balloon is 30 mph, it is possible to use a single trolley-type overhead contact system. The 4/0 AWG cadmium copper contact wire is suspended directly from single-track cantilever structures. Structure configurations are similar to that used for the RTT except that the crossarms are simpler as a result of only having to support the single conductor. A counterweighted system with 3-span overlaps is used.

Because of the sharp curvature (7°30') and contact wire sag considerations, the maximum span length is 70'. The interface between the trolley equipment of the Balloon and the compound equipment of the RTT is accommodated by a short section of Style 5A simple catenary. For sectionalizing purposes, a 50-kV section break and bypass switch is provided at the Balloon turnout from the RTT.

One-Mile Catenary Test Section

One of the more challenging aspects of the project was the design of the catenary Test Section. It is located on the RTT and features easy replacement and testing of alternate catenary configurations. Originally a 2-mile Test Section was envisaged, with provisions for four alternate configurations, which could be interchanged with the Style 5 in-place equipment. However, early in the project it was found that such a scheme would be cost-prohibitive. The selected configuration is a 1-mile long Test Section with allowance for two alternate catenary styles which can be interchanged with the RTT Style 5 catenary. The Test Section is located on a section of tangent track at the southwest portion of the RTT. Portal structures are used from which both the Style 5 equipment and the alternate catenaries are supported (Figure 7 and 8). The support structures are designed to accommodate both constant-tensioned and fixed equipment. Counterweight assemblies with adjustable stops are provided at all termination points and are designed to allow for the transfer of the equipment. An interior overlap is included for purposes of testing catenary overlaps.

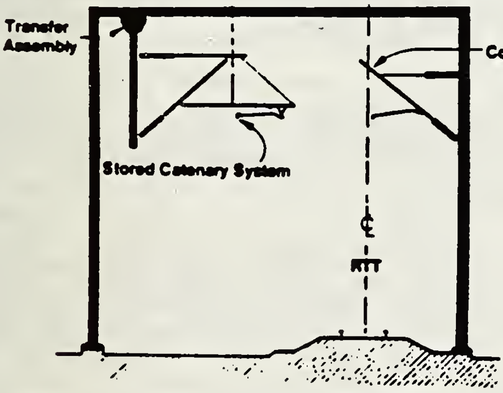


Figure 7: Catenary One-Mile Test Section-Portal Structure

Figure 8: Catenary One-Mile Test Section

The catenaries tested initially were Styles 1 and 3, as are those used on the NECIP. Both are fixed-termination type catenaries. Style 1 (Figure 9) is a heavy compound system consisting of a 4/0 AWG Copperweld stranded messenger, a 4/0 AWG copper solid, grooved auxiliary, and a 336.4-kcmil cadmium copper solid, grooved (deep section) contact wire. Style 1 equipment is representative of that presently being used between Washington and New York on the NECIP. Style 3 (Figure 10) is a "hanging beam," heavy-compound catenary consisting of a 5/8-inch steel-stranded messenger; a 4/0 AWG copper, solid, grooved auxiliary; and a 4/0 AWG cadmium copper, solid, grooved contact wire - all suspended by a 7/8-inch steel-stranded support wire. The Style 3 equipment represents the overhead equipment presently in use between New York and New Haven on the NECIP.

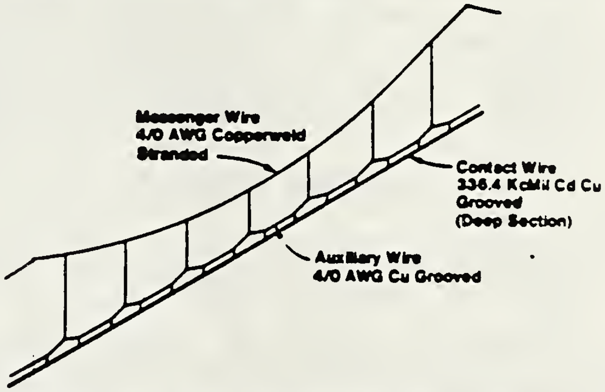


Figure 9: Heavy Compound Catenary (Style 1)

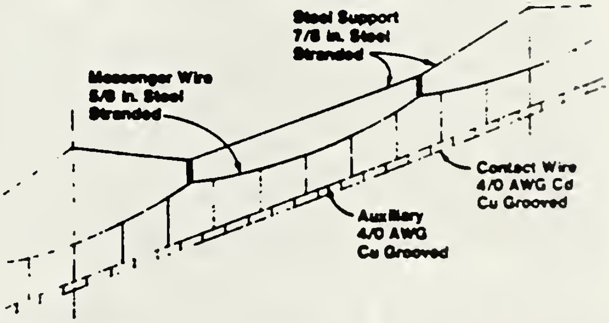


Figure 10: Heavy Compound or "Hanging Beam" Catenary (Style 3)

The fact that all three styles incorporated in the Test Section have different basic span lengths, special consideration was taken in the design. Ideally, a Test Section allowing for variable span length is required, but it was felt that this would be impractical. Therefore, it was agreed to utilize a span length of 250 feet as an intermediate length between the 210 feet for Style 5 and the 300 feet for Style 3. Of course, having extended Style 5 beyond its design maximum span of 210 feet introduces operational restraints during times of high windage. The extended Style 5 equipment through the Test Section is designated Style 5X.

The Style 5X equipment is supported by crossarms attached directly to one leg of the portal. The crossarms are almost identical to those used for Style 5 except that they have the capability of rotating 90° about the portal leg in order to accommodate the changeover of the in-running catenary over the tracks of the RTT.

The stored catenaries are supported by crossarm assemblies attached by means of a Transfer Assembly to the portal crossarm. Each assembly utilizes steel wheels which roll along the bottom flange of the portal beam and with clamping mechanisms which fix the unit in position. The Catenary Transfer Assemblies were specially designed for the project and required development work. Preparatory to final production of the units, full-scale load and performance tests were conducted on a prototype.

In order to bring the stored equipment "into-running" over the RTT, it is first necessary to swing the Style 5X "out-of-running". This is done by lifting the counterweight at one end of the tension section and lowering the counterweight at the other end, which causes the crossarms to rotate around the portal leg. Once the Style 5X is swung out and tied off, the stored equipment is unlocked and moved across the portal by means of the transfer assemblies. When the equipment is in the proper position over the RTT track centerline the transfer assemblies are locked into place. After final adjustments, the catenary testing can commence.

The utility of the Test Section design is that catenary systems can be interchanged in the off-track stored positions without interfering with vehicle operation on the RTT. The only time that interruption of traffic occurs is while the Style 5X OCS is being swung out and the stored OCS is moved into position.

One limitation of the Test Section which was difficult to avoid was the interface between the constant-tensioned Style 5 equipment and the fixed (non-counterweighted) Styles 1 and 3. The thermal expansion the fixed equipment causes the contact wire to move up and down relative to the floating constant-tensioned Style 5 contact wire. Thus, acceptable overlap conditions would only exist over fairly narrow ranges of ambient temperature. In the present testing, the Styles 1 and 3 are being floated using the counterweights, and records are kept of the temperature at the time of testing for correlations to actual fixed conditions as exist on the NEC.

The Test Section is designed to accommodate other overhead contact systems desired for testing. One probable candidate system is an all-aluminum system, in which the DOT/FRA have sponsored research.

TESTING

Considerable testing on the overhead contact system was carried out, both as part of the design and commissioning of the electrification project, and as a result of testing of the equipment to be used on the NEC. A brief discussion of this testing follows.

Pole testing

As a result of economic considerations and in keeping with the desire to provide a readily adjustable overhead contact system, standard wide flange steel sections were selected for use as support poles for the majority of the test track electrification. A limited number of pre-stressed concrete poles was incorporated for study purposes.

Previous studies had shown that the use of steel building design codes such as AISC for the design of OCS support poles tended to be overly conservative. Therefore, in keeping with the spirit of the design code, a more sophisticated design method was developed which more precisely predicted the behavior of the steel poles. Extended buckling equations were utilized, which modeled the load-deformation behavior of wide flange sections in free-standing cantilever applications. In addition, attention was paid to the partial restraint introduced by the return wire attached to the top of each pole.

In order to verify the pole designs a program of full-scale laboratory testing was conducted. Several pole specimens were subjected to load conditions simulating those to be encountered in the field. The specimens were fully instrumented in order to measure load-deflection and stress-strain properties. Loads were applied in steps up to the ultimate loadings. At each step, the pole deflection at the top of the pole and the strain near the base of the pole were measured. The failure mode was lateral torsional buckling reflected by excessive deflection of the pole without increase in load, localized deformation near the base of the pole, and permanent deformation of the pole after removal of load. The test measurements were plotted as load-deflection and stress-strain graphs, and the recorded ultimate loading was in close agreement with the design calculation.

By utilizing a more sophisticated design approach, supported by adequate testing, a considerable economy in structure cost was realized in comparison to that resulting from conventional designs.

Conductor Testing

Because of the high-speed requirements of the catenary system and the critical nature of the conductors in the system performance, an extensive program of conductor testing was carried out. This included routine testing for confirmation and determination of electrical/mechanical properties, as well as special testing for determination of strength and creep properties at elevated temperatures.

As described above, there are quite a variation of conductor types within the various catenary systems. The conductors consisted of bronze alloy, copperweld-copper, hard drawn copper and ACSR of varying sizes and strandings. Solid grooved bronze and hard drawn copper conductors were used for the contact wires. A stranded steel support wire was also used in the Style 3 catenary.

From the standpoint of catenary design and performance, the important conductor properties are: size, material, stranding, diameter, area, weight, strength, elastic and thermal modulii, resistance, hardness, and creep. All of these properties must be known for proper design of the catenary system. Of special concern are: conductor diameter for establishing structure loadings and span lengths (blowoff); conductor area and hardness for evaluating wear; strength for determining catenary tensions; and elongation and creep properties for determining installation requirements.

Due to cyclic electrical loading encountered in electrified operations, it was necessary to perform specialized cyclic testing for determination of creep properties of the conductors. Representative conductors were subjected to cyclic temperature conditions varying between 0°F and 162°F over a 100 hour period. Tests were conducted at constantly maintained tension levels of 30, 50 and 70 percent of the ultimate strengths. As would be expected, the resulting creep was considerably greater than the constant room temperature creep normally specified for conductors. Also, contrary to popular belief the creep of copper or bronze conductors can be quite significant.

The importance of creep on catenary performance cannot be overemphasized. For fixed (variable tension) catenary systems such as Styles 1 and 3 used on the NECIP the creep can result in loss of tension and reduced dynamic performance requiring retensioning of the catenary at considerable expense. For constant tensioned systems, creep can result in additional crossarm swing, causing off-track displacement of the contact wire, which would require increased maintenance for readjustment of the catenary system. By precisely determining the creep properties the creep effects can be compensated for both in the design and in creep-removal prestressing of conductors during installation.

Performance Testing

Extensive performance testing of the overhead contact system was carried out as a result of the commissioning of the electrified installation, as well as of the testing of equipment to be used on the NECIP (Ref 2).

The tests were conducted using an instrumentation car in combination with a pantograph test car fitted with a dead-line pantograph, and which were instrumented to measure and record the following parameters: contact force; contact wire height and stagger; pantograph head trajectory; structure location; loss of contact; and train speed and time. In addition, video recording equipment was provided. The test coach was pulled by a diesel locomotive with a maximum test train speed capability of 120 mph.

Following installation, slow speed commissioning tests were conducted and minor adjustments were made to the catenary in order to insure satisfactory clearances and minimize "hard spots" in the catenary.

Utilizing the test train, deadwire testing was conducted on the various sytles of catenary. Results of the testing showed considerably better performance of the Style 5 catenary over the Styles 1 and 3 presently used on the NECIP. As an example: the percentage loss of contact at 120 mph for Style was less than one percent as compared to 6 percent for Styles 1 and 3. In fact the results showed that the Style 3 catenary is toally unacceptable for continuous use at speeds in excess of 90 mph (Ref 2). The instrumentation was set to compute all losses greater than 2 milliseconds and the static pantograph uplift force was 20 pounds. A one-percent loss-of-contact was considered to be the criterion for acceptable performance.

In general, the performance of the Style 5 overlaps was not signficantly less than the catenary outside of the overlaps. Poorer performance was found at the overlaps at the test section between the constant tensioned Style 5 and the fixed termination Styles 1 and 3. This was due in part to the problem of overlapping a constant tensioned (fixed contact wire height) system with a fixed termination (variable and contact wire height) system. If this condition is encountered in future designs, some additional considerations must be given to providing a satisfactory transition between the different catenary systems.

Both the British and German phase breaks were tested extensively for possible use on the NECIP (Ref 2). During passes at increasing speeds, the two phase break installations were closely monitored for contact force at the pantograph. The maximum allowable force was felt to be 125 pounds. During the first runs, the maximum force on the German phase break was 100 lbs, in the speed range of 60 to 120 mph, whereas the force at the British phase break was in excess of 125 pounds. Considerable damage to the pantograph carbon occurred, apparently due to improper profiling of the contact wire on both sides of the British phase break and was the reason for the excessive contact force. Further evaluations are required.

Additional phase break testing was conducted to examine the possibility of "pass through" without locomotive de-energization. The phase break center sections were ungrounded and energized, while running through the phase break was only permitted at speeds in excess of 60 mph.

In addition, dual-voltage tests were conducted with 25 kV at one end and 12.5 kV at the other. Track magnets were used for the automatic voltage change-over of the locomotive. Phase-to-phase testing was carried out utilizing opposing phases at 25 kV.

Films were made of the passage of the pantograph over the phase-break to study the arcing. The general conclusion was that arc severity increases with decreasing speed and increasing current and voltage. Damage to the phase break and pantograph units under the arcing conditions was considered minimal.

A considerable amount of testing was performed at the TTC on different designs of pantographs (Ref. 2). It was generally concluded that the single-stage pantograph was only marginally acceptable in the Style 5 catenary at a speed of 120 mph, whereas the dual-stage pantograph gave acceptable performance at the same speed for both Styles 1 and 5, but not Style 3. It was recommended that a reduction in head mass would be beneficial for the performance of both pantographs.

The Government conducted design verification tests for the power supply system (Ref. 2) using the traction 7.2-kV transformer tertiary, "buck", connected to one of the 12.5-kV secondary windings. This allowed for the direct application of reduced voltages to the overhead system using the impedance of the overhead contact system (connected line-to-rail) to self-limit the current to approximately design-current capacity: about 640 amperes. The objectives of these tests were to verify the electrical characteristics of the RTT catenary system with the design parameters and to check levels of earth/ground potentials for personnel safety. Results of the tests are shown in Table I. Low test values for the overhead loop impedance can be attributed to the fact that the overhead system and rail configuration are not radial, but that the ground/return conductor and rail are in parallel (a ring) providing multiple-return paths for traction return currents. Other results were quite satisfactory and all earth/ground potentials were measured to be within safe values. The traction power supply system was returned to its operating configuration and operated satisfactorily during extensive testing of AEM-7 locomotives at 12.5 kV and 25 kV.

Table I - Design Verification Test Results

	Design Value	Test Value
Impedance, Style 5 (ohm/mi)	0.349+j0.756	0.226+j0.668
Current Distribution,		
Style 5		
Messenger	39.58%	40.25%
Auxiliary	17.09%	15.10%
Contact	43.33%	44.65%
Ground Current	36%	35%

References:

(1) Report No. FRA/TTC-81-01, "Dead Line Testing of the Faively Single and Dual Stage Panographs on the RTT Catenary System", Transportation Test Center, February, 1981.

(2) Report TTC-11(FR), "Testing of the RTT Electric Supply Systems and the Determination of Electric Characteristics", Transportation Test Center.

BIOGRAPHY

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Khan, Ajmal

The Design Basis for the North Jersey Coast Line Electrification Extension

#126/#127

Prepared by:

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INTRODUCTION

The State of New Jersey is carrying out a major railroad electrification program. In this effort, New Jersey Transit (NJ Transit) is rebuilding 200-track miles of commuter lines at a cost approaching $700 million. One part of this capital improvement program is the electrification of the North Jersey Coast Line (NJCL).

The NJCL is primarily a heavy rail commuter line running from Bay Head into New York City and is operated by the New Jersey Transit Corporation. Conrail have freight rights over part of the route.

It originates at the Northeast Corridor (NEC) in Rahway, New Jersey. The first 8-mile section of the route, from Rahway to South Amboy, has been electrified since 1936, drawing power from the NEC system which is currently operating at 12 kV/25 Hz. A five-mile extension of the electrification to Matawan was completed in 1982, using the same feeding system as the NEC. Most recently, NJ Transit has decided to electrify an additional 16 miles of the NJCL from Matawan to Long Branch and to provide this section with a new signal and communication system. Long Branch Yard will be rebuilt as an electrification terminus with a storage yard for electric trains. In addition, repair of three overwater bridges will be coordinated with the electrification activity. A map of the route is shown in Figure 1.

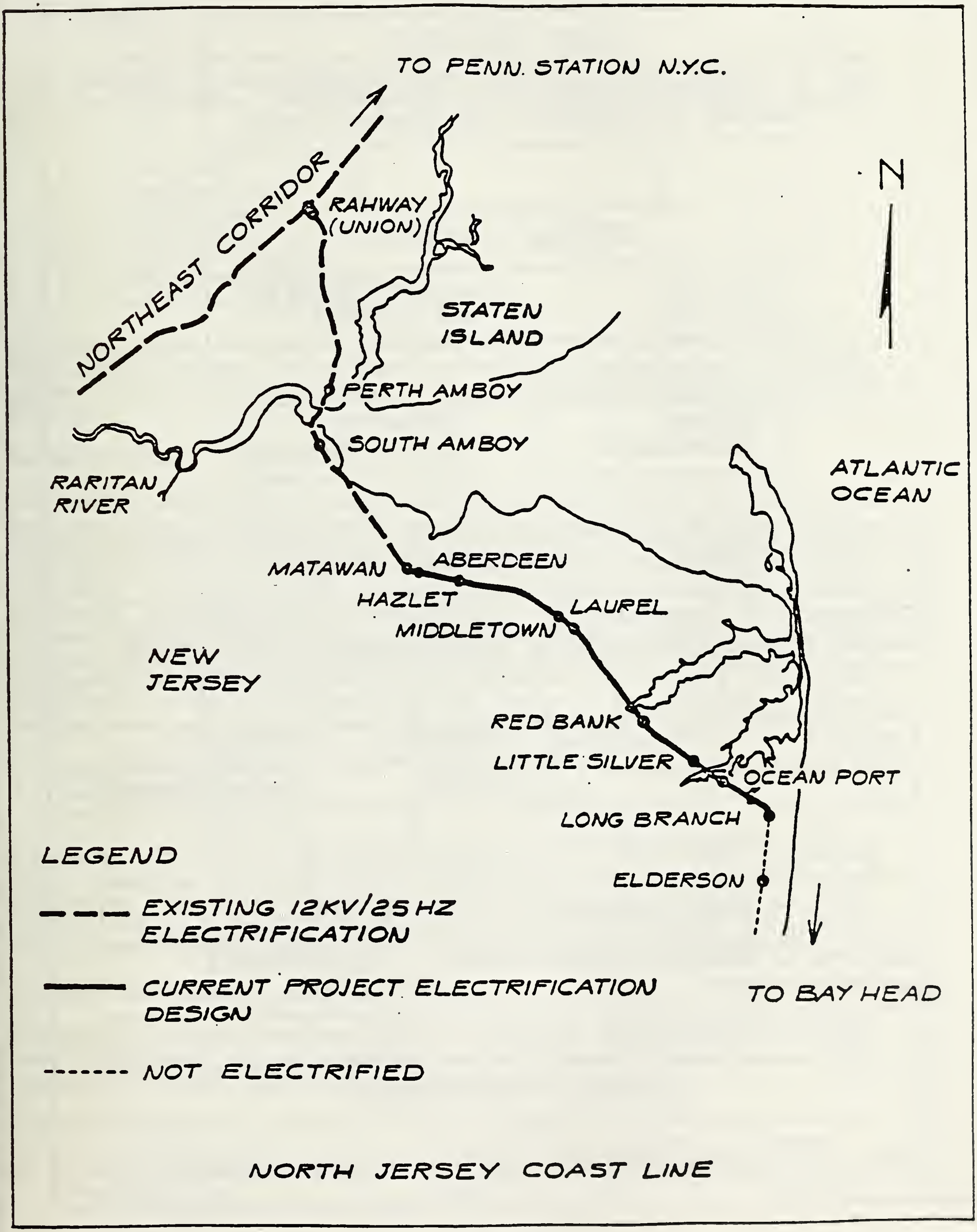
As a result of this electrification program, the travel time on the NJCL will be reduced due to the superior performance of the electric trains, elimination of time consuming engine changes for most trains, and increased track speeds permitted by the introduction of a new signaling system. Additionally, on-time performance will be improved as the proposed centralized traffic control system will allow better regulation of train operations.

The studies and design effort required to formulate the power supply and catenary systems for the Matawan to Long Branch electrification are the subject of this paper. The work proceeded as shown in the Flow Chart, Figure 2, and resulted in the preparation of detailed engineering drawings, calculations and specifications.

TRACTION POWER STUDY

Electrification engineering design has to be preceded by a study which defines the overall power requirements, system parameters, utility interfaces, substation and switching station locations, and ratings for the catenary and major electrical equipment. Accordingly, a traction power study was performed by EMJ/Electrack at the outset of this project to define these elements. The results from this study were used as the basis for the detailed engineering design for the NJCL.

At the beginning of the electrification project, NJ Transit specified that the catenary system had to be energized via traction power substations along the route at a voltage of 12.5 kV and at the commercial frequency of 60 Hz. However, it was stipulated that the traction system should be designed in such a way as to be readily convertible to 25 kV operation at some later date. Consequently, the substation equipment and the catenary system are specified to be insulated at 25 kV to ground which is equivalent to 46 kV class equipment and requires a Basic Insulation Level (BIL) of 250 kV.


TO PENN. STATION N.Y.C.
NORTHEAST CORRIDOR
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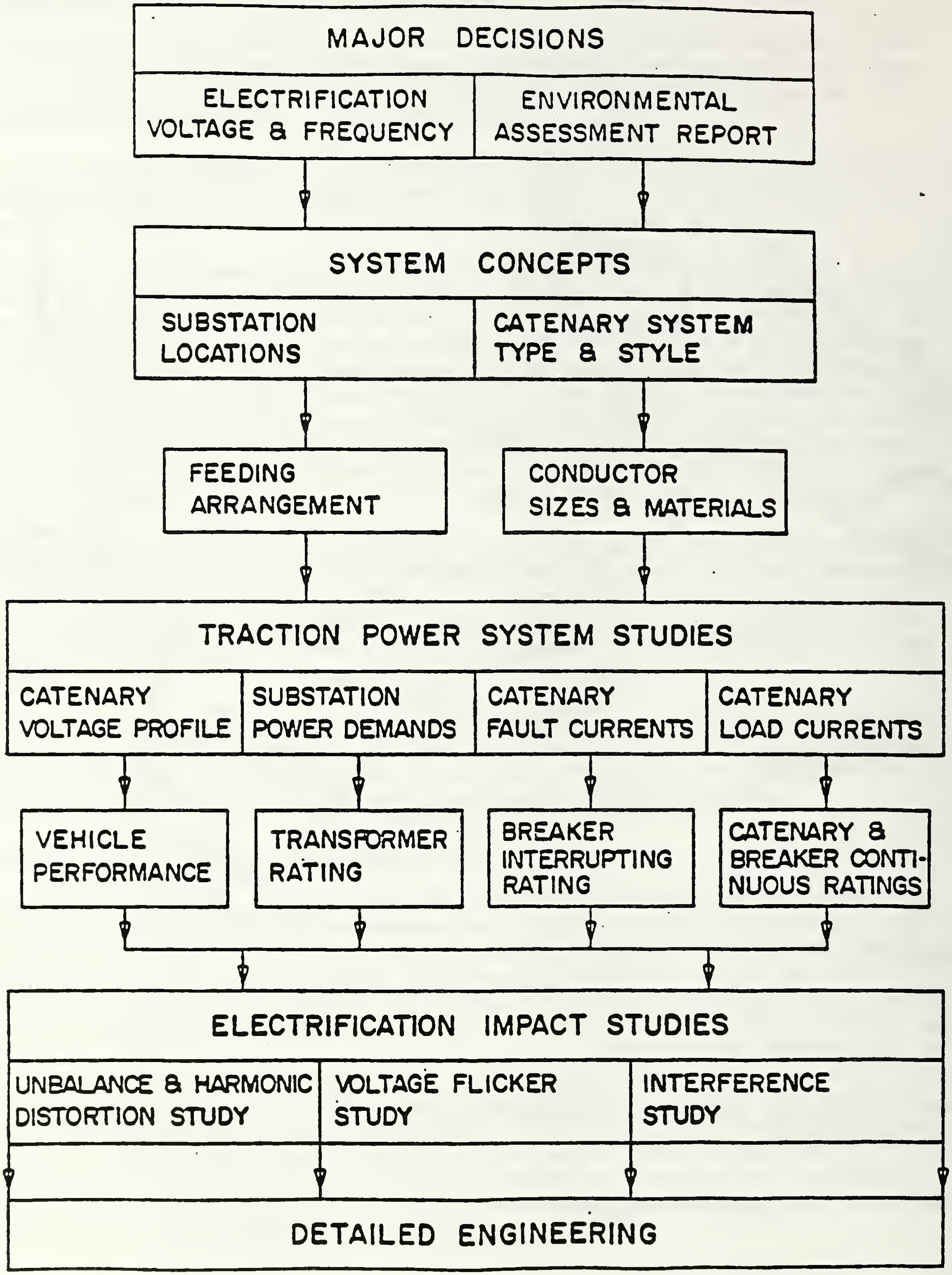
ATLANTIC OCEAN
MATAWAN
ABERDEEN
HAZLET
LAUREL
MIDDLETOWN
NEW JERSEY
RED BANK
LITTLE SILVER
OCEAN PORT
LONG BRANCH
ELDERSON
TO BAY HEAD
LEGEND
– – – EXISTING 12KV/25HZ ELECTRIFICATION
—— CURRENT PROJECT ELECTRIFICATION DESIGN
------ NOT ELECTRIFIED
NORTH JERSEY COAST LINE

FIG. 1


MAJOR DECISIONS
ELECTRIFICATION VOLTAGE & FREQUENCY
ENVIRONMENTAL ASSESSMENT REPORT
SYSTEM CONCEPTS
SUBSTATION LOCATIONS
CATENARY SYSTEM TYPE & STYLE
FEEDING ARRANGEMENT
CONDUCTOR SIZES & MATERIALS
TRACTION POWER SYSTEM STUDIES
CATENARY VOLTAGE PROFILE
SUBSTATION POWER DEMANDS
CATENARY FAULT CURRENTS
CATENARY LOAD CURRENTS
VEHICLE PERFORMANCE
TRANSFORMER RATING
BREAKER INTERRUPTING RATING
CATENARY & BREAKER CONTINUOUS RATINGS
ELECTRIFICATION IMPACT STUDIES
UNBALANCE & HARMONIC DISTORTION STUDY
VOLTAGE FLICKER STUDY
INTERFERENCE STUDY
DETAILED ENGINEERING

FLOW CHART REPRESENTING THE DESIGN OF POWER SYSTEM FOR NJCL

FIG. 2

Power Demand

Power demand for the 16-mile, two-track line was calculated using a computer program which simulated the performance of both multiple unit (MU) consists and E-60 locomotive hauled trains. The input used to calculate the total power demand consisted of:

- Track profile
- Train speed limits
- Train consists
- Tractive effort
- Total power demand
- Voltage and current limits
- Future operating schedules.

Two types of trains were considered and three separate traffic scenarios, provided by NJ Transit, were simulated. The maximum 5-second power demand, together with the 1-minute, 15-minute, and 30-minute rms MVA and average power factors are presented in Table 1.

Substation Spacing

The computer program also calculated the location of substations and switching stations, giving the spacing between the power sources. For this project, the location of two substations and one of the switching stations had already been recommended under the study for the Environmental Impact Statement completed in June 1978. The initial task consisted of confirmation of the suitability of the location of these three sites and selection of the location of the fourth site for a switching station. Based on the maximum catenary voltage of 12.5 kV and allowable dip to 8.5 kV, at which level the MU's lose propulsion power and the performance of the E-60 has decreased to an unacceptable level, the locations for the substations and switching stations were determined. The three recommended sites were found to be acceptable, and the second switching station was located at Laurel Avenue. The distances between the sites are:

Aberdeen to Laurel	5.6 miles
Laurel to Redbank	5.7 miles
Red Bank to Long Branch	4.0 miles

It is worth noting that, for 12.5 kV 60 HZ operation, the voltage drop is the limiting factor. Depending upon the train load, the substations need to be 8 to 11 miles apart when feeding a double-track system and 4 to 6 miles apart for a single-track system. However, when the system is converted to 25 kV 60 Hz, the NJCL system will be able to supply beyond Long Branch from Red Bank and up to South Amboy from Aberdeen.

Traction Power Equipment and Catenary Rating

A further main purpose of the power study is to determine the parameters for the major electrical equipment and the catenary system which are adequate to meet the NJCL system requirements. A summary of these ratings is as follows:

Traction Transformer	10 MVA OA; (with overloading capability up to 250%)
230 kV 2-pole circuit beaker continuous rating	1600A

Substation Power Demands and Average Power Factors

	POWER DEMANDS AND POWER FACTORS					
	5 sec	1 minute	15 minutes		30 minutes	
	MVA	MVA	MVA	COS Ø	MVA	COS Ø
Scenario 1						
Red Bank to Long Branch	13.1	11.6	5.0	0.68	4.7	0.69
Red Bank to Laurel	11.6	9.7	5.2	0.69	4.4	0.70
Total Substation	14.7	12.6	8.1	0.69	6.8	0.71
Aberdeen to Laurel	12.0	9.7	3.8	0.72	3.4	0.72
Aberdeen to South Amboy	11.6	8.9	5.0	0.74	3.7	0.75
Total Substation	13.1	11.5	6.1	0.73	5.5	0.73
Scenario 2						
Red Bank to Long Branch	15.7	12.6	6.5	0.64	6.0	0.64
Red Bank to Laurel	14.5	14.1	6.2	0.64	6.1	0.64
Total Substation	27.0	26.7	11.4	0.64	10.3	0.66
Aberdeen to Laurel	12.6	11.9	4.4	0.66	4.3	0.65
Aberdeen to South Amboy	10.0	6.5	3.4	0.75	2.9	0.77
Total Substation	15.8	14.2	6.5	0.71	6.1	0.72
Scenario 3						
Red Bank to Long Branch	15.7	14.6	6.5	0.63	4.8	0.69
Red Bank to Laurel	12.6	12.5	5.0	0.66	4.9	0.66
Total Substation	28.3	21.1	9.9	0.65	8.2	0.67
Aberdeen to Laurel	12.6	12.6	5.1	0.64	5.1	0.64
Aberdeen to South Amboy	12.6	8.0	4.3	0.72	4.1	0.73
Total Substation	22.9	18.4	8.1	0.69	7.9	0.69

TABLE 1

Interrupting rating	20,000 MVA
Vacuum circuit breaker	
continuous rating	1200A
Interrupting rating	500 MVA

Catenary System:

4/0 hard drawn copper equivalent messenger wire
300 MCM hard drawn copper equivalent trolley wire
3/0 ACSR stranded ground wire
131 lb. rail section

Details of the catenary system are described in later sections.

UTILITY SUPPLY

The whole of the NJCL electrification extension lies within the territory operated by Jersey Central Power and Light Company (JCP&L). The utility is to provide primary supply to the two substations and auxiliary power supply to all four sites.

Selection of Primary Voltage

The utility network is comprised of primary transmission at 230 kV with secondary transmission at 34.5 kV. There are no intermediate voltages, within the JCP&L system in the vicinity of the NJCL. As a result of the voltage flicker studies, which are described later, it was determined that supply to the NJCL substations would be made at 230 kV. Additionally, JCP&L has plans to build the 230 kV loop between Red Bank and Freneau Substations to include a new intermediate substation to be located at Taylor Lane. Further, JCP&L wants to utilize the NJ Transit right-of-way along the coast line for this future loop connection.

The 230 kV connection from the JCP&L Red Bank Substation to the NJ Transit Red Bank traction substation is about ½ mile long. At the other end of the line, the distance between the JCP&L Freneau Substation and the NJ Transit Aberdeen traction substation is about 2 miles long. These connections will be designed and built by JCP&L as 3-phase lines. Switchyards will be constructed adjacent to each of the two NJ Transit substations so that JCP&L can loop in and out at each yard and extend the lines to Taylor Lane in the future. The extension to Taylor Lane, presently planned for 1992, will improve the security of supply to each of the NJ Transit substations such that, in the event of a major fault, both substations can be fed from either of the utility substations at Freneau or Red Bank.

Voltage Unbalance and Harmonic Distortion

The magnitude of the single-phase traction loads and the distortion due to harmonics generated by electric trains require that a study be carried out to calculate the effects on the JCP&L three-phase system. The input data for this computer study was obtained from the 1½-hour morning and evening rush periods of the NJCL train operation simulation, under the worst possible estimated conditions of utility transmission line and transformer outages.

Traction systems use single-phase loads which cause voltage unbalance in a balanced 3-phase utility supply, resulting in negative phase sequence (nps) current flows in the utility system. Induction motors and synchronous machines present a relatively low impedance to negative phase sequence currents and this can lead to undesirable heating effects in these machines.

Modern thyristor controlled electric vehicles create non-sinusoidal load currents which generate harmonics in the AC system feeding the catenary. The circulation of these harmonic currents may cause excessive heating in capacitors and unacceptable core losses in transformers which could result in maloperation of many items of equipment in use by other utility consumers.

The limits of unbalance and distortion used for the study were based on JCP&L Standards, and are:

	LIMIT	STUDY VALUE
Voltage unbalance	3%	1.35%
Negative phase sequence current	5%	0.33%
Individual harmonic voltage magnitude	1%	0.82%
Total harmonic voltage distortion	3%	1.34%

The results of the study show that the JCP&L system stands up well to the imposed traction loads even under various onerous outage conditions. Voltage and current unbalance and distortion are well within the acceptable limits and no remedial action is necessary.

Voltage Flicker

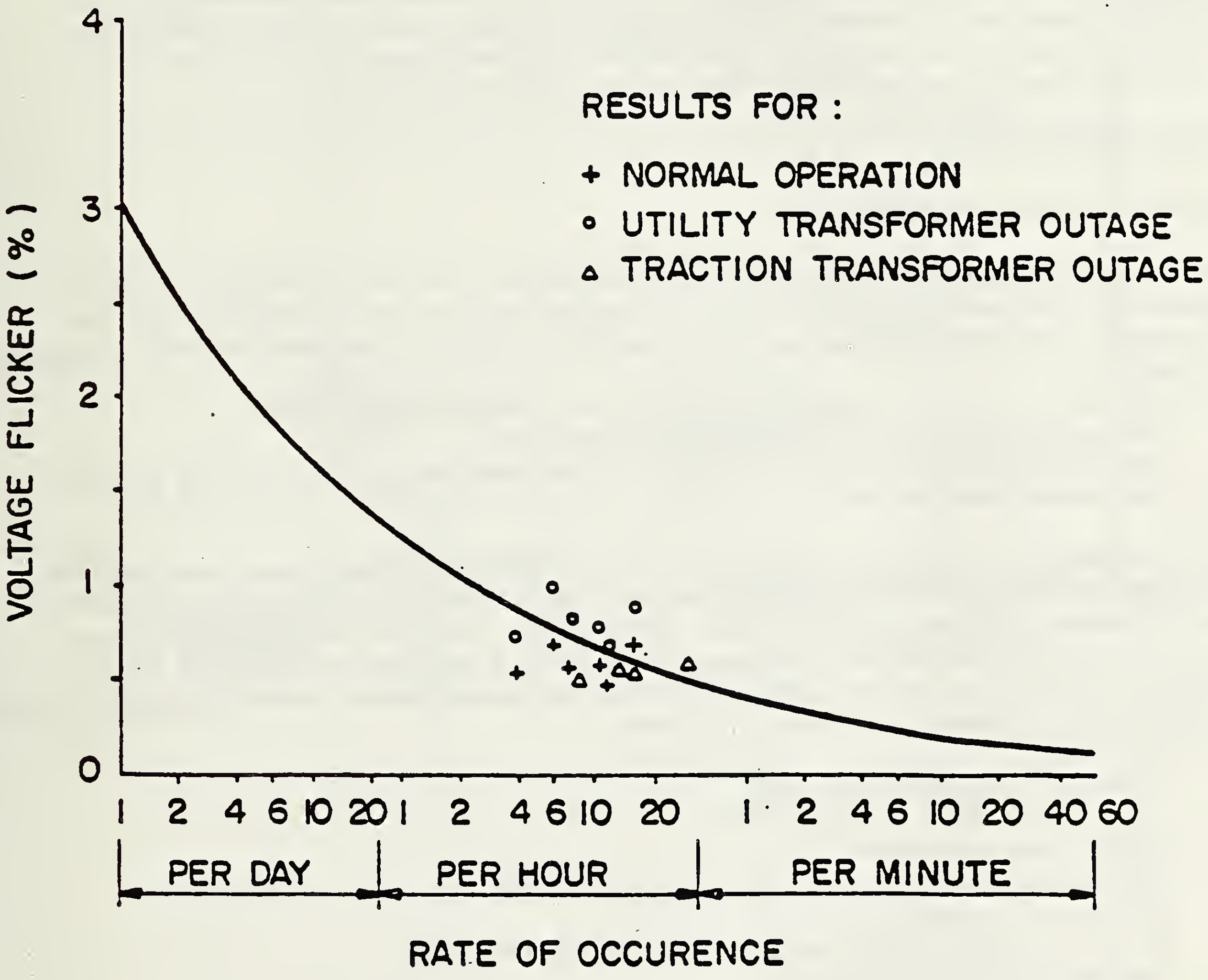
Due to the proximity of suitable lines, together with lower construction costs, it was originally proposed that Red Bank and Aberdeen Substations be supplied from the JCP&L 34.5 kV subtransmission system. The proposed lines had relatively high fault levels (low source impedance) and, in addition, calculations of unbalance and distortion due to the traction loads showed that JCP&L's acceptable limits were not exceeded. However, JCP&L felt that the commuter trains, which frequently accelerate and stop during the two rush periods, would cause voltage fluctuation on the distribution system. Voltage flicker evaluations for the traction loads were carried out for the two substations by developing instantaneous volt drop calculations (5-second loads) for the three previously described scenarios. The results were plotted as a graph of volt drop against number of occurrences and compared with the JCP&L "Voltage Flicker Limit Curve", which is shown in Figure 3.

The graph shows that voltage flicker due to commuter train traffic is on the borderline of the JCP&L Limit Curve. Under some conditions of outage, the voltage drop exceeds the Curve and JCP&L were concerned that voltage flicker could cause annoyance to other customers in the heavily populated area surrounding the NJCL and also adversely impact some of the electronic equipment in industries located near the line. To alleviate these concerns, NJ Transit agreed to take their supply from the JCP&L 230 kV transmission system.

Auxiliary Supply

Auxiliary supply is fed from two separate utility sources at each of the two substations. Complete redundancy has been designed into the system because it was considered particularly important that the following loads should have minimal or no interruption for safe operation of NJCL:

- Signaling system power supply



BORDERLINE CURVE OF VOLTAGE FLICKER ACCEPTABILITY AND STUDY RESULTS

FIG. 3

- Supervisory control and data acquisition
- Station service, including DC battery
- Station security.

The auxiliary line voltages are 4.8 kV 60 Hz three-phase for Red Bank and 4.16 kV 60 Hz three-phase for Aberdeen.

The primary purpose of the auxiliary power is to supply station power and feed the signal power motor-generator sets which convert the frequency from 60 Hz to 100 Hz. All signaling equipment operates at a frequency of 100 Hz to prevent interference from the 60 Hz traction power supply system. An automatic transfer switch (ATS) ensures quick transfer, in the event of an outage, from the de-energized source to the alternative source. The one-line diagram of the auxiliary power is shown in Figure 4.

DETAILED POWER DESIGN

Substation and Switching Station

The power study established the need for two substations and two switching stations. The substations feed power at 12.5 kV 60 Hz through vacuum circuit breakers to the catenary system. The switching stations carry out three principal functions, namely:

- provide improved voltage regulation by paralleling the catenaries
- ensure separation of different electrical sections
- permit alternative feeding facilities in the event of power loss from one of the normal sources.

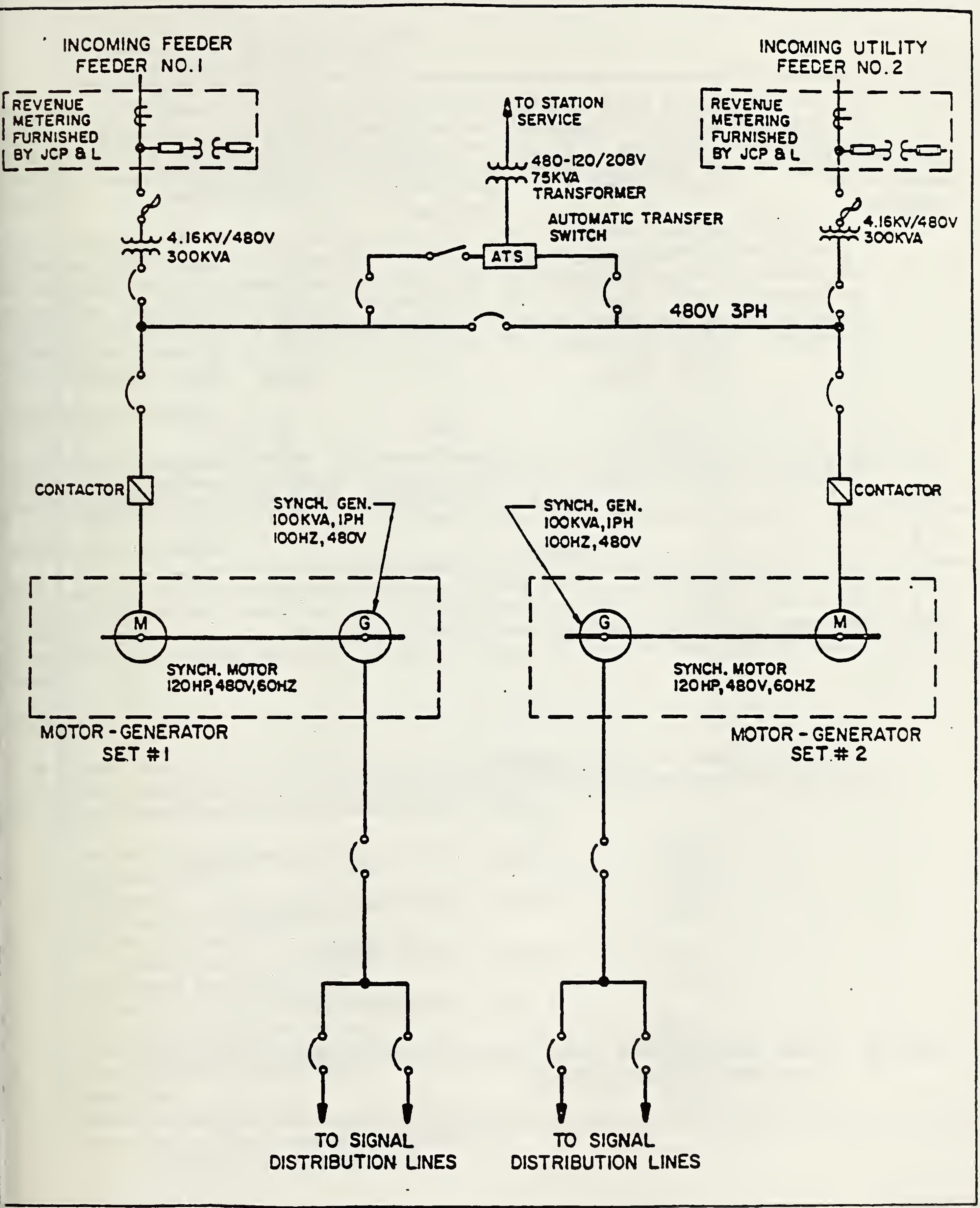
The feeding arrangement for the NJCL is shown in Figure 5. Phase breaks are to be installed in the catenary at each substation and switching station location to provide for separation between different supply phases. This means that the phase breaks in the catenary, and the outgoing circuit breakers, could have a maximum voltage of 46 kV across them for a 25 kV operating system. These unique requirements need a specialized approach during design, some aspects of which are:

- Fluctuating single phase loads
- High voltage feed to substations
- Single phase equipment
- High frequency of faults on the catenary system
- Rail return currents
- Interface with communications and signaling systems
- Electromagnetic Interference
- 100 Hz signal power.

Substation Layout

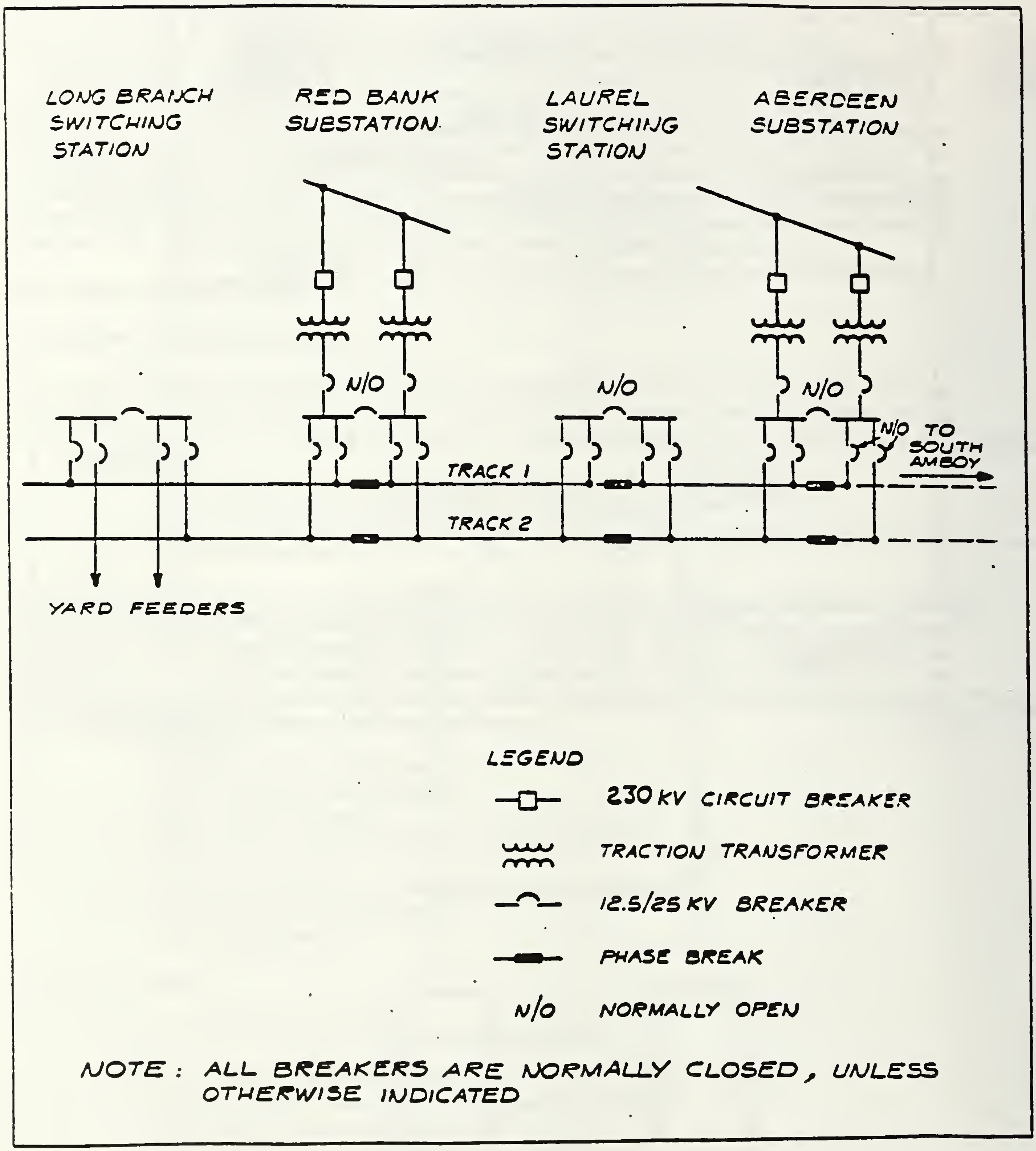
Each substation contains the following major equipment:

- 230 kV 2-pole SF6 circuit breakers
- 230 kV/25-12.5 kV two winding traction transformer
- 230 kV 2-pole disconnect switch
- 230 kV single phase high speed grounding switch
- 230 kV busbars
- 12.5 - 25 kV busbars & disconnect switches



SIGNAL POWER - ONE LINE DIAGRAM

FIG. 4



NOTE: ALL BREAKERS ARE NORMALLY CLOSED, UNLESS OTHERWISE INDICATED

FIGURE 5

- 12.5 - 25 kV vacuum switchgear
- Motor-generator sets.

Figure 6 and 7 show, respectively, the one line diagram and the equipment layout of Aberdeen Substation. The 230 kV incoming line and the double bank design have resulted in the need for a large substation compound. The size, 250 ft. by 120 ft., is dictated by the large separations necessary for equipment and busbars operating at a voltage of 230 kV.

The orientation of the substation and layout of the equipment was governed by the incoming 230 kV transmission lines and the 12.5 - 25 kV outgoing feeders to the catenary. In addition, the motor-generator sets for signal power supply are located within the substation. Each substation has an adjacent 230 kV switchyard, which is operated by JCP&L. The main function of the switchyard is to act as a switching point for the three-phase 230 kV incoming and future outgoing lines. The metering equipment is housed in the switchyard.

MAJOR EQUIPMENT

The major equipment, because of the specialized applications required for traction power, includes some unique design features. A brief outline of the more significant parameters of each piece of equipment follows:

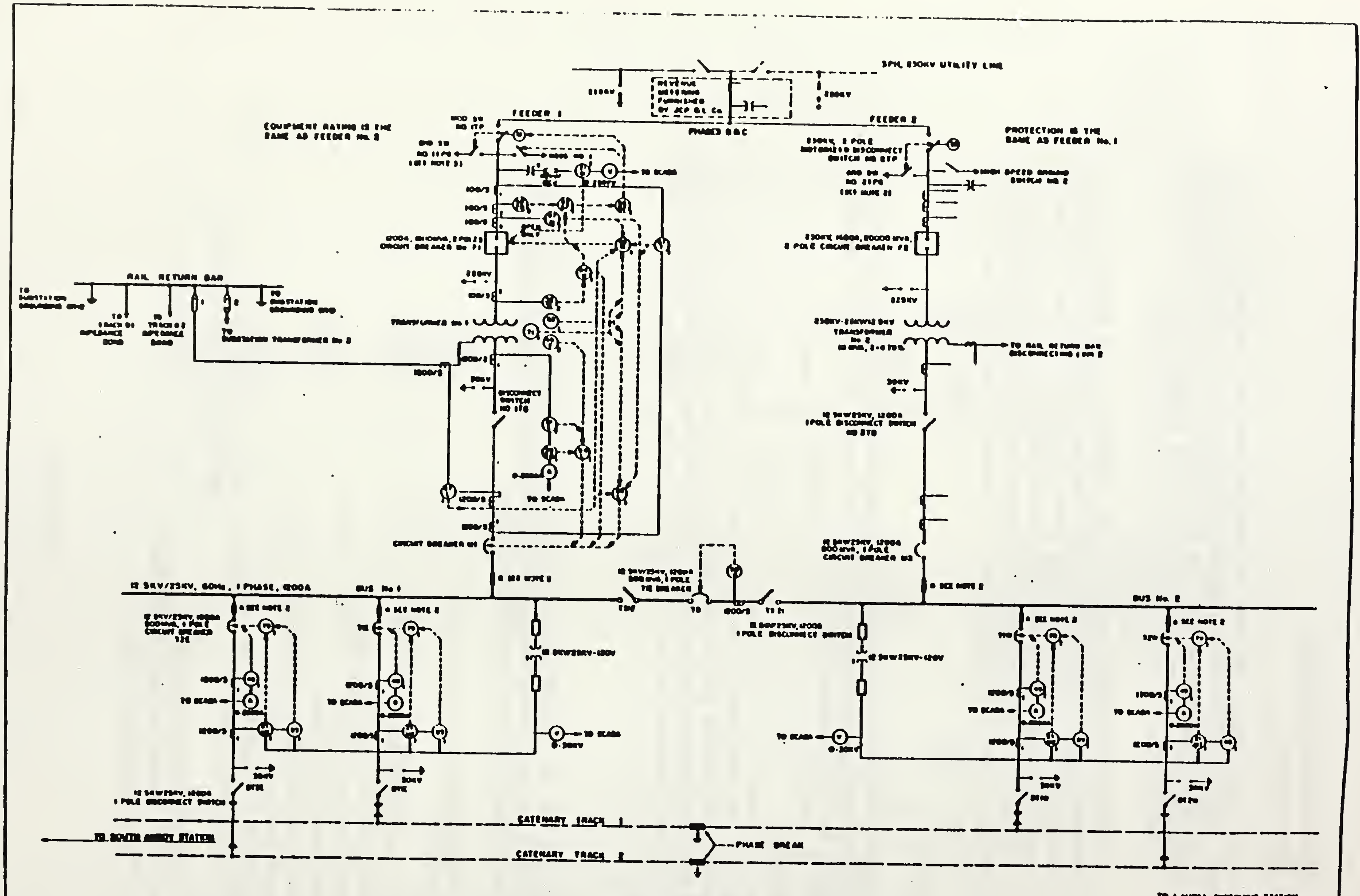
230 kV Circuit Breaker

The specification calls for design and delivery of four 230 kV, 60 Hz, sulfur hexafluoride (SF6) circuit breakers, associated current transformers and relay cabinets. The circuit breakers will be installed outdoors and will be of the single-phase, double-pole type. The circuit breaker will be connected across two phases of the incoming 230 kV utility feeder.

Ratings

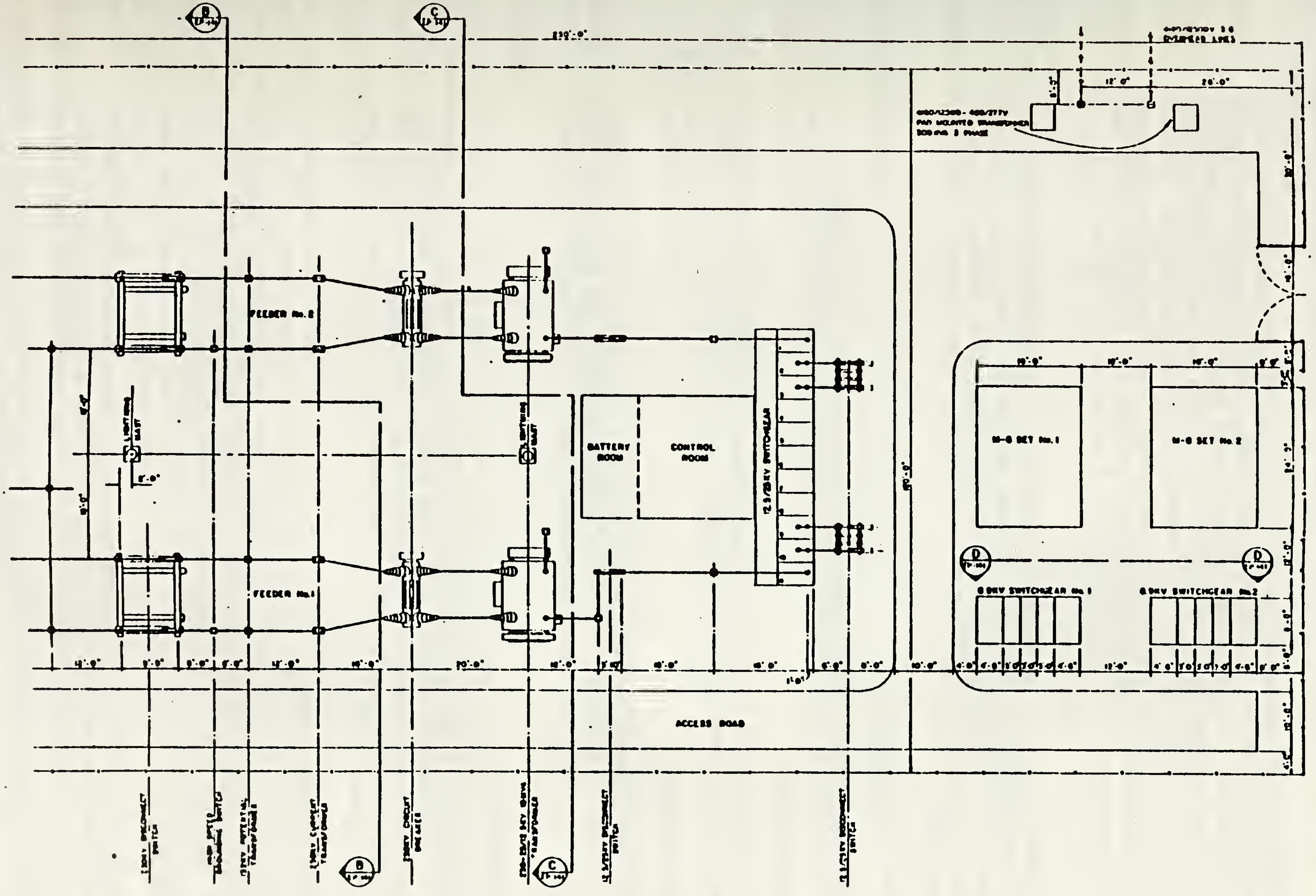
The circuit breakers will be manufactured in accordance with the latest revisions of NEMA and ANSI/IEEE standards which relate to the required ratings and capabilities of AC High-Voltage Circuit Breakers and will be as follows:.

Nominal voltage class	230 kV
Maximum voltage	242 kV
Frequency	60 Hz
Continuous current at 60 Hz	1600 A
Symmetrical short circuit current at rated maximum voltage	50 kA
Interrupting time (60 Hz basis)	3 cycles
Assymetrical interrupting capability at rated maximum voltage	60 KA
Closing and latching capability	80 KA
Capacitance switching current	500 A
Rated BIL	900 kV
Minimum creepage distance of bushing	220 inches
Number of c-o operations without compressor or hydraulic system operations	4



TRACTION POWER
ABERDEEN SUBSTATION
ONE LINE DIAGRAM

FIG. 6



ABERDEEN SUBSTATION
EQUIPMENT ARRANGEMENT PLAN

FIG. 7

Capability

The circuit breaker will be capable of completely interrupting any current from zero to its rated interrupting current in three cycles on both phases, when faulted by any type of fault. Each circuit breaker will be capable of interrupting the line charging current with essentially strike free performance. If a restrike or re-ignition occurs, the resultant over-voltage is not to exceed 2.5 the times normal line to ground voltage. To limit switching transient overvoltages to a value not exceeding 2.5 times normal line to ground voltage, each circuit breaker will be equipped with preinsertion resistors. The circuit breakers will be electrically and mechanically trip free and will be of the dead tank design.

Each circuit breaker is to have its mechanism operated by pneumatics, hydraulics or a combination of both methods. Sufficient storage will be provided in the operating system for four (4) successful complete "close-open" operations starting at normal working pressure, without the compressor replenishing gas, oil or nitrogen between or during these operations.

230 kV Protective Relaying Scheme

The following protective relays are to be provided with the 230 kV circuit breaker.

Under Voltage Protection

Under voltage relaying will be provided to prevent closure of the 230 kV circuit breaker when the incoming utility power line is de-energized.

Breaker Failure Protection

An instantaneous over current relay will be used as a fault detector in combination with a timer relay. In case of a breaker failure, the overcurrent relay will detect the fault and, after a selected delay introduced by the timer relay, it will close the high speed grounding switch.

Over Current Protection

Over current protection will be provided by using Inverse Definite Minimum Time (IDMT) relaying with an instantaneous element to protect against transformer over currents. The instantaneous element will protect up to 80 percent of the transformer winding. The IDMT element will cover the remaining 20% of the winding and will provide back-up for uncleared 12.5/25kV system faults.

Instantaneous High Impedance Relay

An instantaneous, high impedance type ground fault relay will be used to protect the traction transformer against high voltage winding faults. This relay will work on the balanced current principle and will be connected in parallel across two C.T.'s.

Traction Transformer

The power demand study, which considered various outage contingencies and rush period demands, indicated that the traction transformers should have a rating of 10 MVA each. The secondary side will operate initially at 12.5 kV to ground and in the future at 25 kV to ground. All transformers will be identical and designed for parallel operation at each substation.

Ratings

Continuous nominal rating	10 MVA OA
Overload	250% for one minute
3-phase fault on 230 kV system	20000 MVA
Voltage ratio	230 kV/12.5 kV 230 kV/25 kV
Percent impedance	4.75% on 10 MVA
Basic Impulse Insulation Level (BIL)	900 kV
Voltage Control	No load tap changers with settings at + 10% and - 5%
Temperature Rating	60°C by resistance 75°C by hot-spot in winding

Unusual Operating Duty

Due to frequent accelerations and stops, the commuter trains are seen by the transformer as a highly fluctuating load. The duty cycle adopted for the design of the transformer is as follows:

> 100% load continuously, followed by
> 120% load for 1 hour, followed by
> 150% load for 15 minutes, followed by
> 100% load continuously.

This duty cycle is expected during the two morning and evening peak 1½-hour traffic periods. In addition, to meet an exceptionally high peak, a 250% overload for one minute in each 1½-hour traffic period has been specified.

Harmonics

Thyristor control of modern electric vehicles, generate harmonics within the traction power system which tend to distort the voltage and current waveforms. The effects of overload on the transformer due to harmonics is to be considered by the manufacturer at the product design stage.

Short Circuit Duty

The catenary comprises bare conductors which have limited clearances at overbridges where birds or icicles can cause short circuits, consequently, the transformer lower voltage terminals will be subjected to a high incidence of short circuit faults of varying magnitudes. The transformer has been specified to be properly braced to withstand the many short circuit forces without reducing its required 30-year life. The off-load tap-changing equipment must also be capable of carrying these short circuit currents. In addition to other design tests, NJ Transit requires short circuit tests to be performed on one unit to ensure that the transformer has the required capability to withstand fault currents of various magnitudes.

Transformer Differential Protection

A transformer differential protection relay, with percentage harmonic restraint, will be provided for the protection of the traction transformer.

12.5/25 kV Switchgear

The metal-enclosed vacuum switchgear is to be capable of operation at either 12.5 kV or 25 kV 60 Hz. The circuit breakers in the switchgear will be of the single-phase single-pole type. Vacuum breakers have been selected because of their capability to withstand frequent faults without maintenance, their compact size, and their excellent record of low fire risk.

Substation/Switching Station Switchgear Housing

All vacuum circuit breakers are to be accommodated in a weatherproof metal housing. The housing will be divided into a high-voltage area where the 25 kV portion of the breaker will be located and a front aisle to gain access to the control panel and breaker. The front aisle is to be at least four feet wide so that breakers can be easily removed.

Circuit Breakers

The circuit breaker are to be of the single-phase, single-pole, vacuum type. The switchgear will be of modular design, with prewired units in fabricated metal housings, which can be easily bolted together on site. Each module will accommodate the complete circuit equipment, incorporating both the breaker and the control panel. The breaker will be fitted with vacuum interrupters, capable of making and breaking both load and fault currents. The circuit breakers are to be equipped with an automatic reclosure, which will consist of a two stage reclosing relay; instantaneous and time delay.

Rating

The rating of the circuit breakers will be as follows:

Type	Metal-enclosed vacuum type
Nominal voltage class	46 kV (3-phase equivalent) 12.5 kV to ground initially 25 kV to ground in future
Frequency	60 Hz
Rated maximum phase to phase voltage	48.3 kV
Low Frequency withstand voltage	105 kV
Impulse crest voltage (peak value)	250 kV
Rated continuous current	1200A
Rated short circuit current at rated maximum voltage (27.5 kV)	20 kA
Maximum symmetrical interrupting capability	32.3 kA

Rated interrupting time	5 cycles

Catenary Feeder Protection

The main protection for each catenary feeder will consist of a single-phase distance relay having one or two zones with circular mho characteristics and one zone having an offset mho characteristic. In addition, a load blinder relay will be provided to prevent operation of the distance relay during peak load conditions. Faults occurring in the first zone will be cleared instantaneously, whereas faults in the second and third zone will be cleared after a time delay.

Close-up zero voltage faults occurring on closure of the catenary breaker will be detected instantaneously by the offset mho relay, which will also detect a 12.5/25 kV busbar fault "behind" the breaker. Catenary backup protection will be provided by a thermal overload type relay. The thermal characteristics of this relay will approximate to the thermal characteristic of the catenary system. This relay will operate for abnormal overloads or continuous high-impedance faults on the catenary.

Catenary feeder breakers in substations and switching stations will be equipped with an automatic reclosure system, which will include two-stage reclosing relays and associated accessories. The first stage of the relay will be an instantaneous type and the second stage will have an adjustable time delay (0 to to 30 seconds).

Bus-Tie Protection

A high set instantaneous overcurrent relay will be provided that will operate if the circuit breaker is closed onto ground faults. The relay will be operative only during closing operation of the circuit breaker and will be bypassed approximately 500 ms after energization.

Incoming Feeder Protection

A high set instantaneous overcurrent relay with a time delay unit will provide incoming feeder protection. The operation of this relay will be delayed by up to 500 ms to discriminate from Zone 1 of the catenary protection. This time delay will be bypassed for 1 second during the breaker closing operation in order to permit clearing of instantaneous bus faults occurring on energization. An inverse time overcurrent relay will provide backup busbar protection, which will also serve as backup to catenary faults.

An instantaneous, high impedance type ground fault relay will be provided to protect against traction transformer low voltage winding faults. This relay will work on the balanced current principle and will be connected in parallel across two C.T.'s. One C.T. will be in the main breaker bushing and the other in the transformer ground connection.

SIGNAL POWER SYSTEM

Signal power is required to feed signaling equipment, such as track circuits, signal aspect lights and automatic gates at grade crossings. Therefore, a study of the signal power requirements for the NJCL between Union and Asbury Park was carried out to determine the total demand.

The existing electrified section between Union and Aberdeen is presently supplied by a non-synchronous motor generator (M-G) set in the NJ Transit substation located at South Amboy. However, with the modernization of the signaling system from Union to Long Branch, a single integrated synchronous power system is required.
The signal power is to be converted from utility supply sources at 60 Hz to 100 Hz by motor-generator sets, stepped up to 6.9 kV and transmitted along the line, using bare feeder conductors supported on the catenary poles. A frequency of 100 Hz is utilized to adequately discriminate signaling track circuit currents from the 60 Hz propulsion return currents in the rails.

Signal Loads

The values of the signal loads from Union to Asbury Park were used for the study. Figure 8 shows the distribution of these loads along the line, which can be summarized by section as follows:

Union to South Amboy	39 KVA
South Amboy to Aberdeen	65 KVA
Aberdeen to Long Branch	80 KVA
Long Branch to Asbury Park	16 KVA
Total	200 KVA

Based on these loads and possible future expansion of signaling requirements, NJ Transit decided to install four 100 KVA rated motor-generator sets. Two M-G sets will be located in each of Aberdeen and Red Bank Substations. The location of the M-G sets and the associated 6.9 kV 100 Hz switching equipment can meet the power demand even in the unlikely event of an outage of two M-G sets in the system. The single line and sectionalizing of the signal power system is shown in Figure 9.

Frequency Conversion Equipment

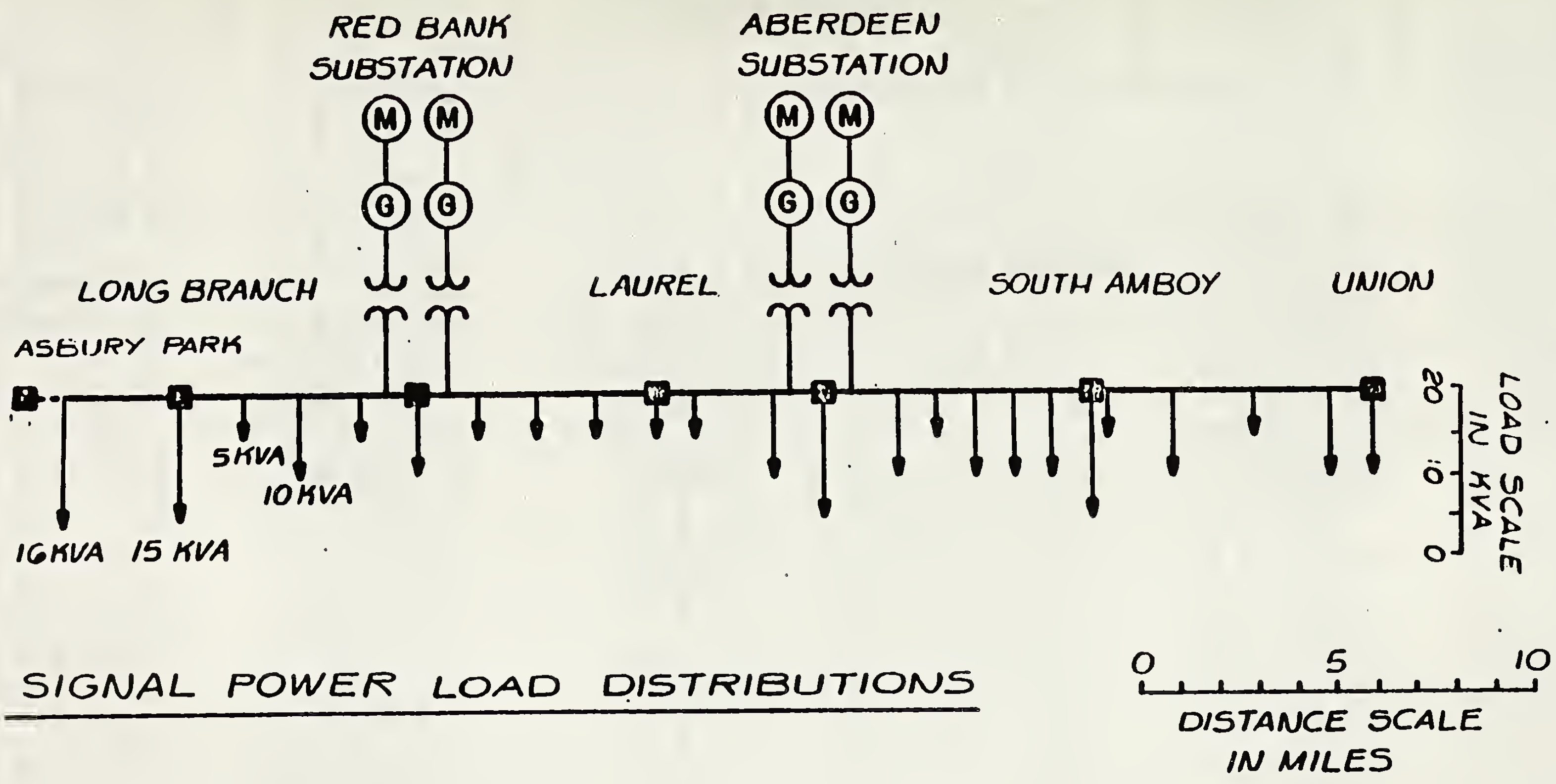
Power at 480 V, 60 Hz is fed to a 120 HP 3-phase synchronous motor which is mechanically coupled to a synchronous generator. The 100 KVA single-phase generator output of 480 V 100 Hz is transformed via a step-up transformer to 6.9 kV 100 Hz for distribution. The M-G set and the step-up transformer are protected by circuit breakers.

Each M-G set, together with its associated switchgear and control circuits, is to be packaged in a weatherproof housing, which is to be assembled, wired, and factory tested prior to shipment to site.

SUPERVISORY CONTROL & DATA ACQUISITION SYSTEM

As a result of modern technology, the cost of computers and communication systems is declining almost exponentially, thus making the remote monitoring and controling of equipment cost effective. Consequently, all substations, switching stations and interlockings on the NJCL will be unmanned. The Supervisory Control and Data Acquisition (SCADA) System will allow continuous monitoring of most of the major equipment with consequent decision making, diagnostics and fast restoration of the system following an electrical fault being much simplified.

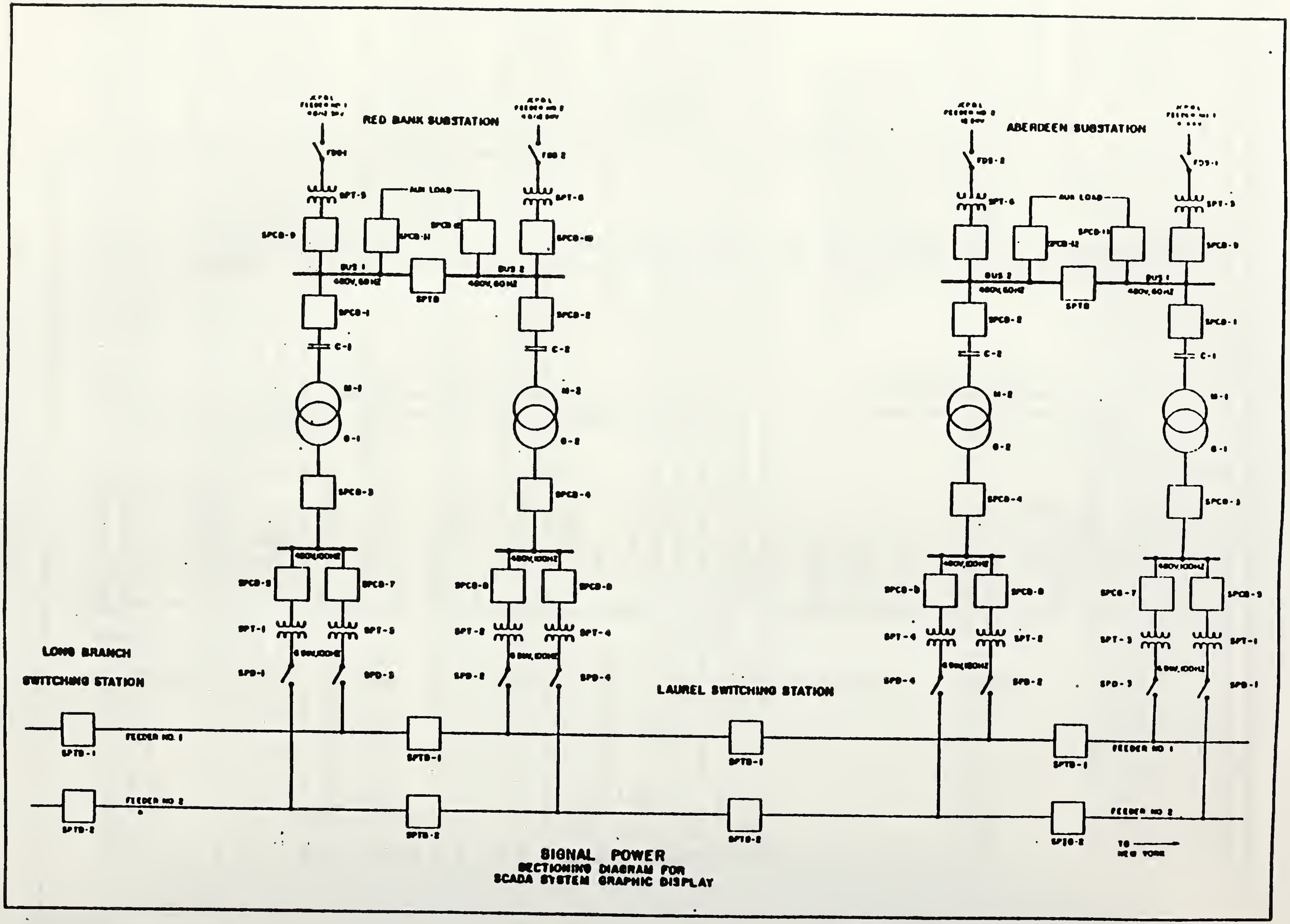
NJ Transit presently has an operating SCADA system, which was installed for the Morris and Essex (M-E) Line. The master station for the M-E Line is located in Hoboken, NJ. The equipment was designed and installed by Bristol-Babcock and placed in service in



SIGNAL POWER LOAD DISTRIBUTIONS

NOTE : ALL LOADS ARE ASSUMED TO HAVE 0.9 POWER FACTOR (LAGGING). WITH THE LOAD VALUE INDICATED BY THE LENGTH OF THE ARROWS.

FIG. 8



SIGNAL POWER
SECTIONING DIAGRAM FOR
SCADA SYSTEM GRAPHIC DISPLAY

FIG. 9

September 1984. It is proposed that the SCADA system for the NJCL is added to this existing equipment.

Control, Indication and Alarms

The existing SCADA system provides remote control of the high voltage circuit breakers, a majority of the low voltage circuit breakers, and many disconnect switches. The status of all controlled devices is reported, with alarm conditions being annunciated on an individual station basis. Other functions which are performed are interlocking and data logging, blocking, and status displays on both a large display board and CRT's.

Graphic Display

The graphic display board in Hoboken shows all lines, feeders, catenary disconnects, circuit breakers, switches, transformers and other traction and signal power equipment. Circuit breakers and switches are indicated by red, green and amber light emitting diodes (LED's). There is room for expansion on the display board, which is equipped with its own micro computer and distributed multi-plexer (D-MUX).

Computer System

The computer system is configured with complete back-up capability and has two central processing units (CPU's). These are Digital Equipment Corporation PDP 11/34 computers with 32k RAM and the memory of each has been expanded by the addition of a RAM clip. A teletype machine is provided, together with two printers, one to log operations and the other for non-routine print-outs. Three CRT's, two for graphic display and a third for programming, display detailed one line diagrams and also tabulate data. Three keyboards, two for day-to-day operation and a third for emergency conditions, are also provided. Automatic switching from normal communications line to back-up is also provided, with modems, transmitting at a rate of 1200 baud, for each telephone line.

The PDP 11/34 uses the DMOS operating system. Integrated with a time generating board, the DMOS runs the command program, which acts as a watch dog for the SCADA system, by performing routine polling of pilot points at the remote stations and periodic update of the display board and data base. The status from the remote unit formats the message to the printer and CRT. The worse case response time for a status change to be detected is in the range of 2.5 seconds.

Remote Terminal Units

The remote terminal units (RTU's) are Bristol-Babcock Index 4000, which are equipped with RFL modems for each of the two 4-wire telephone lines. For the NJCL extension, fifteen RTU's are required for control, indication, alarm and telemetering purposes. At the substations and switching stations, each RTU has one or two interfacing cabinets (IFC) to display the status of the equipment under local control mode. The IFC also contains interface circuitry for control, indication, alarm and telemetry.

Master Station

The existing master station at Hoboken Control Center will be extended to supervise the new electrification on the NJCL. Hardware additions, which will be similar to the existing equipment will provide additional data base, but will leave the software essentially "as-is". To improve the relatively slow response time, the computer will be upgraded with additional memory. The mosaic tile display board is to be modified to include the traction power, catenary, signal power, and interlockings from Union to

Long Branch. The newly electrified system one-line diagrams, together with alarms and data logging, will also be shown on CRT's.

CATENARY SYSTEM CONFIGURATION

The study phase of the modernization and electrification of the NJCL included the analysis of alternative catenary systems and selection of the style of catenary and structure type providing the best value from a cost and operating standpoint. Included in the study were:

- o Establishment of baseline criteria
- o Identification and evaluation of catenary alternatives
- o Identification and evaluation of structural alternatives
- o Cost analysis of alternatives
- o Identification of style of system for special cases
- o Recommendation of style of catenary and structures to be utilized.

The results of the traction power supply and signal power supply studies determined the electrical characteristics of the system. The catenary is designed for initial operation at 12.5 kV/60 Hz, with provision for future conversion to 25 kV/60 Hz. However, initial values for insulation are suitable for 25 kV to avoid future retrofit. Signal power distribution lines are designed for operation at 6.9 kV/100 Hz and this system will not require modification when the catenary is converted to 25 kV.

A major concern in selecting the catenary alternatives was visual impact. To minimize intrusion of the system, emphasis was placed on clean lines and simplicity so the conductors, support and registration assemblies and structures selected are as unobtrusive as possible. An assessment of the impact of the addition of utility transmission lines on the size of catenary poles and foundations lead to an early decision by NJ Transit to discount this option. However, positioning of the catenary poles provides sufficient room for the addition, at a later date, of a JCP&L transmission line on separate poles.

The four catenary styles investigated were all Simple Catenaries, each comprising two wires - messenger and trolley. The system height, or depth, of the catenaries was kept as low as possible to further reduce visual impact. One alternative utilized fixed termination (FT) or variable tension catenary. The other three alternatives utilized automatic tensioned (AT) or constant tension catenary, all of which incorporate a pre-sagged trolley wire for better dynamic performance.

Structure types evaluated included poles fabricated from wide flange steel, tubular steel, concrete and wood. Foundation analysis covered augered concrete pier foundations, driven steel caissons, driven steel piles, and direct embedment. Only selected structural combinations were evaluated since compatibility of pole and foundation had to be maintained.

SYSTEM REQUIREMENTS AND CRITERIA

The first step in system selection is to establish the basic criteria under which all candidate systems must be evaluated. This forms a common design baseline and provides the operating parameters for the system.

Basic Criteria

A maximum vehicle operating speed of 79 mph is dictated by the civil and operating constraints of the NJCL. This operating speed is applicable to both locomotive hauled and multiple unit consists, which may operate with up to five pantographs in contact with the trolley wire. 79 mph is not an unusual speed for a catenary system, however, the requirement for five pantographs operating does impose additional design constraints. Multiple pantographs can create dynamic conditions in the catenary which must be considered when trying to achieve satisfactory current collection at each pantograph.

Several design features were incorporated in the system to improve the dynamic performance of the catenary. One was to maintain a trolley wire tension as high as practicable while staying within the allowable safety factors under all climatic and worn wire conditions. Higher tension in the trolley serves to limit the amplitude of the traveling wave set up in the wire by moving pantographs. The amplitude of the reflected wave from the registration is also reduced by this higher tension. Pre-sagged trolley wire is also important in improving dynamic performance, see Figure 10. The concept of pre-sagging is that the dynamic pantograph pressure only raises the trolley at midspan to a near level condition, thereby reducing the apparent resilience of the wire and reducing the effect of the hard-spot at the registration point. Pre-sagging provides smoother current collection and is frequently used for high speed or multiple pantograph operations.

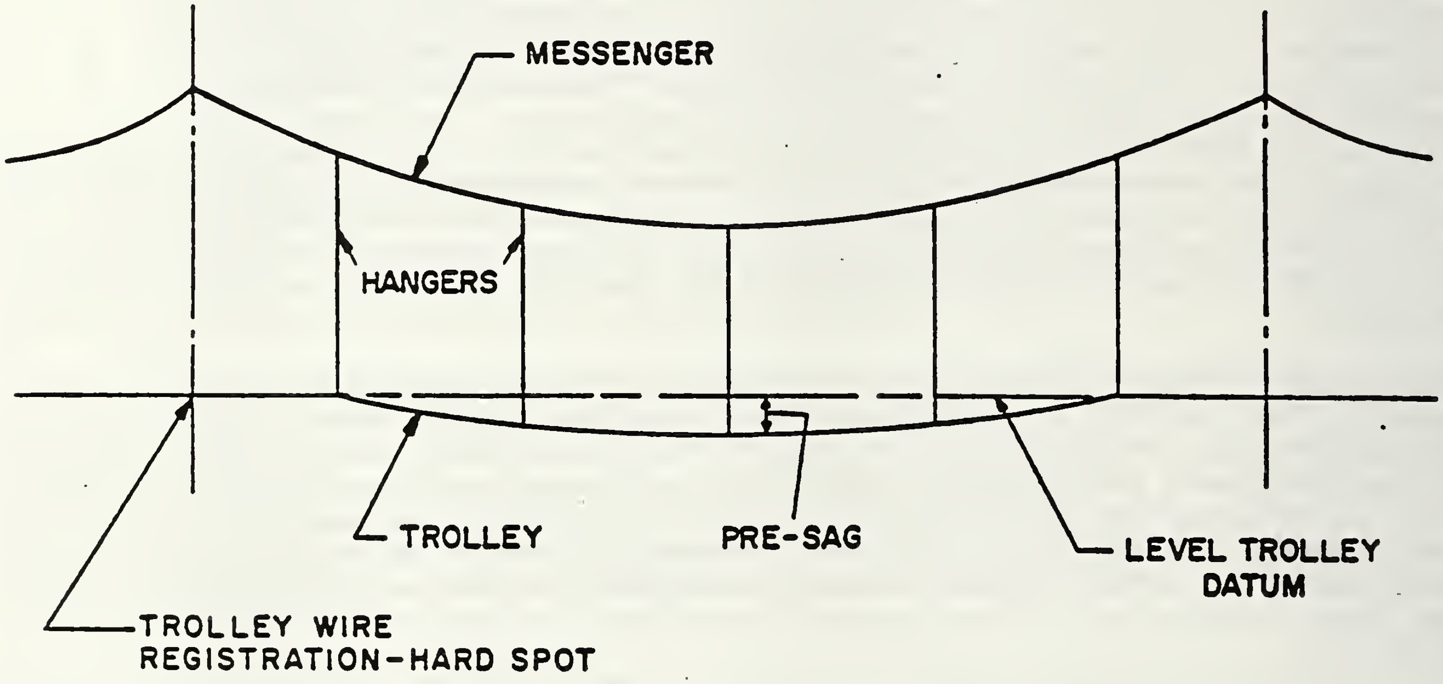
Another means of improving system dynamic performance is the introduction of odd-span lengths at certain intervals. The purpose of the odd span is to create a different span oscillation amplitude and frequency which breaks up the traveling wave created by the pantographs and tends to mitigate the possibility of the catenary reaching a resonant state. The odd-span can also serve as a natural catch-up span when allowing for structure spacing and was easily incorporated on the NJCL, without significant cost impact, due to the number of grade crossings, undergrade and overhead bridges, and other normal catenary pole obstructions such as passenger stations and turnouts to sidings.

Figures 11 and 12 detail the build-up of figures utilized to determine the maximum stagger, stagger effect and blow-off. AREA recommends assumption of a 3° vehicle roll angle. However, only one-half of the vehicle roll was considered since the probability of the vehicle rolling fully in opposition to the wind during maximum wind conditions is remote. FRA Class 4 track maintenance tolerances were used, and based on the above, a maximum stagger of 6" on tangent and 9" on curved track was established. A maximum in-span wire deviation (stagger effect plus blow-off) of 9.5" was allowed.

Pole deflection due to wind loading under operating conditions was limited to 2" at trolley level. Across track movement of the registration, due to along track movement of the catenary resulting from temperature variations, was limited to 2", and a trolley wire construction tolerance of 0.5" in the across track direction was included.

Climatic Conditions

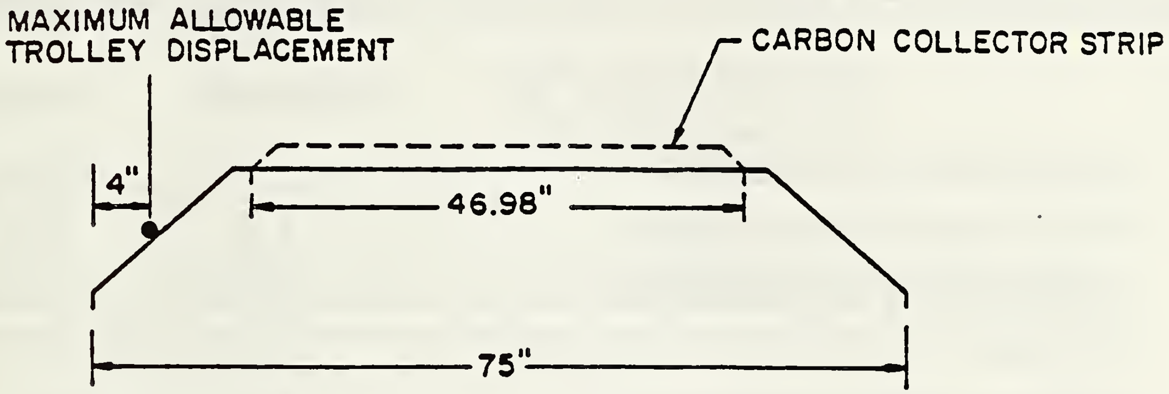
Climatic conditions were evaluated based on National Oceanic and Atmospheric Administration (NOAA) data for the general vicinity of the route. The analysis of this historic data, together with NESC recommended loadings and Jersey Central Power & Light (JCP&L) design criteria, resulted in the adoption of the following operating conditions:



PRE-SAGGED TROLLEY WIRE

FIG. 10

PANTOGRAPH DIMENSIONS



EQUIVALENT DISPLACEMENTS AT TROLLEY HEIGHT OF 22'-6"

FOR JERSEY ARROW III E.M.V. VEHICLE		
LATERAL DISPLACEMENT	2.00"	
CAR BODY ROLL	7.10"	
PANTOGRAPH SWAY	3.19"	
TOTAL VEHICLE	12.29"	
FOR CLASS 4 TRACK	TANGENT	CURVED
ALIGNMENT	1.50"	1.50"
GAUGE	.38"	.50"
CROSS-LEVEL	5.97"	5.97"
TOTAL TRACK TOLERANCE	7.85"	7.97"
EFFECTIVE PAN MOVEMENT AT 22'-6"	20.14"	20.26"

NOTE:

JERSEY ARROW III HAS BEEN USED SINCE THE ROLL CHARACTERISTICS ARE WORSE THAN THE E-60.

FIG. 11

DISPLACEMENTS AT TROLLEY HEIGHT OF 22'-6"

	AT SUPPORT	IN-SPAN
PANTOGRAPH MOVEMENT	20.14"	20.14"
POLE DEFLECTION (WIND)	2.0 "	2.0 "
CONSTRUCTION TOLERANCE	0.50"	0.50"
STAGGER	6.0 "	—
ACROSS TRACK MOVEMENT *	2.0 "	2.0 "
STAGGER EFFECT	—	1.5 "
BLOW-OFF	—	8.0 "
MID-SPAN OFFSET	—	—
MAXIMUM DISPLACEMENT-TANGENT	30.64"	34.14"
INCREASED GAUGE ON CURVE	0.12"	0.12"
ADDITIONAL STAGGER ON CURVE	3.00"	—
DELETION OF STAGGER EFFECT	—	-1.5" †
MAXIMUM DISPLACEMENTS-CURVE	33.76"	32.76"

* DUE TO CANTILEVER SWING RESULTING FROM ALONG TRACK TEMPERATURE MOVEMENT

† EQUAL STAGGERS ON CURVED TRACK

FIG. 12

Ambient temperature range: -10°F to 105°F
Maximum operating wind velocity 55 mph
Operating ice loadings: 1/2" ancillary wires
1/2" messenger wire
1/8" trolley wire,

and for determination of the worst case loadings for structure design, the following non-operating conditions were selected:

60°F, 90 MPH wind, 0" ice
0°F, 40 MPH wind, ½" ice
-10°F, 55 MPH wind, 0" ice.

CATENARY ALTERNATIVES

The catenary system has to supply only a relatively moderate current (852 Amps maximum, 783 Amps RMS) and, for aesthetic reasons, a decision was made to focus on two-wire simple catenary systems and to exclude three-wire compound catenaries.

Wire Sizes

By reference to the output from the Power System Study, a baseline catenary system consisting of a 4/0 copper messenger wire and a 300 MCM copper trolley wire was identified. These conductors provide for good current distribution between the two wires without requiring an excessive size for either wire, and minimizing wire sizes is important for wire blow-off and ice loading considerations. This combination of conductors was designated Style 1 Catenary for the study and the maximum temperature in the conductors was determined to be 51°C which is well below the recommended working limit for copper of 75°C.

In selecting other alternatives, conductors were chosen based on electrical equivalence to the Style 1 conductors. Hence, a 5/8" copperweld-copper composite strand was chosen as an alternative messenger and 350 MCM Bronze Alloy 80 as an alternative trolley wire. The other styles were, therefore:

Style 2: 4/0 HD Copper, 350 MCM Bronze 80, (AT)
Style 3: 5/8" Composite, 350 MCM Bronze 80, (AT)
Style 4: 5/8" Composite, 350 MCM Bronze 80, (FT)

Note that the difference between Styles 3 and 4 is the tensioning system, not the conductors.

Catenaries

Each of the conductor combinations was evaluated to determine the optimum tensions for the range of loading conditions and to derive the maximum permissible span length. Minimum system heights were also established for each catenary style to provide for reduced visual impact consistent with retaining sufficient flexibility for hanger length variation.

The use of high and low temperature stops on the AT catenary was investigated. The function of the low temperature stop is to reduce ice sag and to increase the allowable tension length. By setting the lower temperature stop at +15°F, the allowable half tension length could be increased by 400 feet. However, this resulted in a 10-20%

reduction in maximum span length. The Matawan to Long Branch route was evaluated using the two maximum tension lengths developed under this analysis, namely 5400 feet and 6200 feet. The reduction in the number of overlaps using the longer allowable tension legnth was not sufficient to justify the increased number of structures resulting from the shorter permissible maximum span. Ice sag was not critical in either case.

Upper temperature stops are not considered desirable. The effect of limiting balance weight movement due to high wire temperatures is to reduce tension in the wires. As described earlier, it is preferable to maintain a high trolley wire tension to improve current collection characteristics and, for this project, the temperature variation is not excessive.

Table 2 gives the results of the tension versus maximum span analysis. A minimum factor of safety of 2.0 was utilized for worst case loading conditions which allows for the most adverse climatic conditions coupled with a 30% worn trolley wire.

Table 2

Style	Messenger Tension (lbs)	Trolley Tension (lbs)	Maximum Span (feet)	System Height (feet)
1	4500	3600	240	4.0
2	4500	5500	275	4.5
3	9000	5300	290	3.5
4	7500	5000	225	4.0

Discussion of Alternatives

Style 1 Catenary is an AT catenary utilizing hard drawn (HD) copper conductors. This construction offers a pricing advantage over the other styles. The relatively short 240-foot maximum span offsets this savings to some extent due to the increased number of structures required. The disadvantage of Style 1 is the relatively low tension in the trolley wire when compared to the other styles. This is due to the lower strength of the hard drawn copper by comparison with the bronze alloy conductor.

Style 2 is also an AT catenary. The use of the bronze trolley allows a higher tension, which is advantageous for both dynamic response and maximum span length which is 35 feet longer than Style 1. Bronze trolley also exhibits better wear characteristics when compared to HD Copper. The disadvantage of Style 2 is the larger cross-section of the trolley wire which increases the effective wind loadings on the wire, contributing to blow-off and resultant loads at the support structures. The additional weight of the bronze trolley wire results in an increase in the system height.

Style 3 is an AT catenary which uses a composite messenger and bronze trolley. The higher tension capabilities of these conductors allows spans lengths up to 290 feet, which is useful in reducing the number of structures and allows more flexibility in structure positioning. The use of these conductors increases the cost of the catenary, but this is partially offset by the reduction in the number of structures, foundations and ancillary wire attachments and related construction labor costs. The 3'-6" system depth provides a low profile system with less visual impact than the other AT catenaries.

Style 4 is an FT catenary utilizing the composite messenger and bronze trolley. Maximum span length is limited to 225 feet due to blow-off considerations. The advantage of FT is that balance weight sets are not required to maintain tension in the system. Overlaps are only required at approximately 10,000-foot intervals to facilitate construction, maintenance and tension adjustment. The disadvantage of FT catenary is that the variation in tensions, due to temperature change, result in varying sags and poorer current collection than is provided by the AT systems.

Order of Precedence

From a technical standpoint, the order of precedence for the catenary styles was firstly Style 3, followed by Style 2 and Style 1, and lastly Style 4. Style 3 was ranked the highest due to the high trolley tension for dynamic performance and long span length resulting in a reduction in the number of supports.

Catenary Support and Registration

Various support and registration styles were analyzed to determine the type best suited for use on the NJCL. Criteria for evaluation included:

- Simplicity
- Mechanical independence of the catenaries
- Ability to accommodate temperature movement
- Constructability
- Adjustability
- Aesthetics
- Availability.

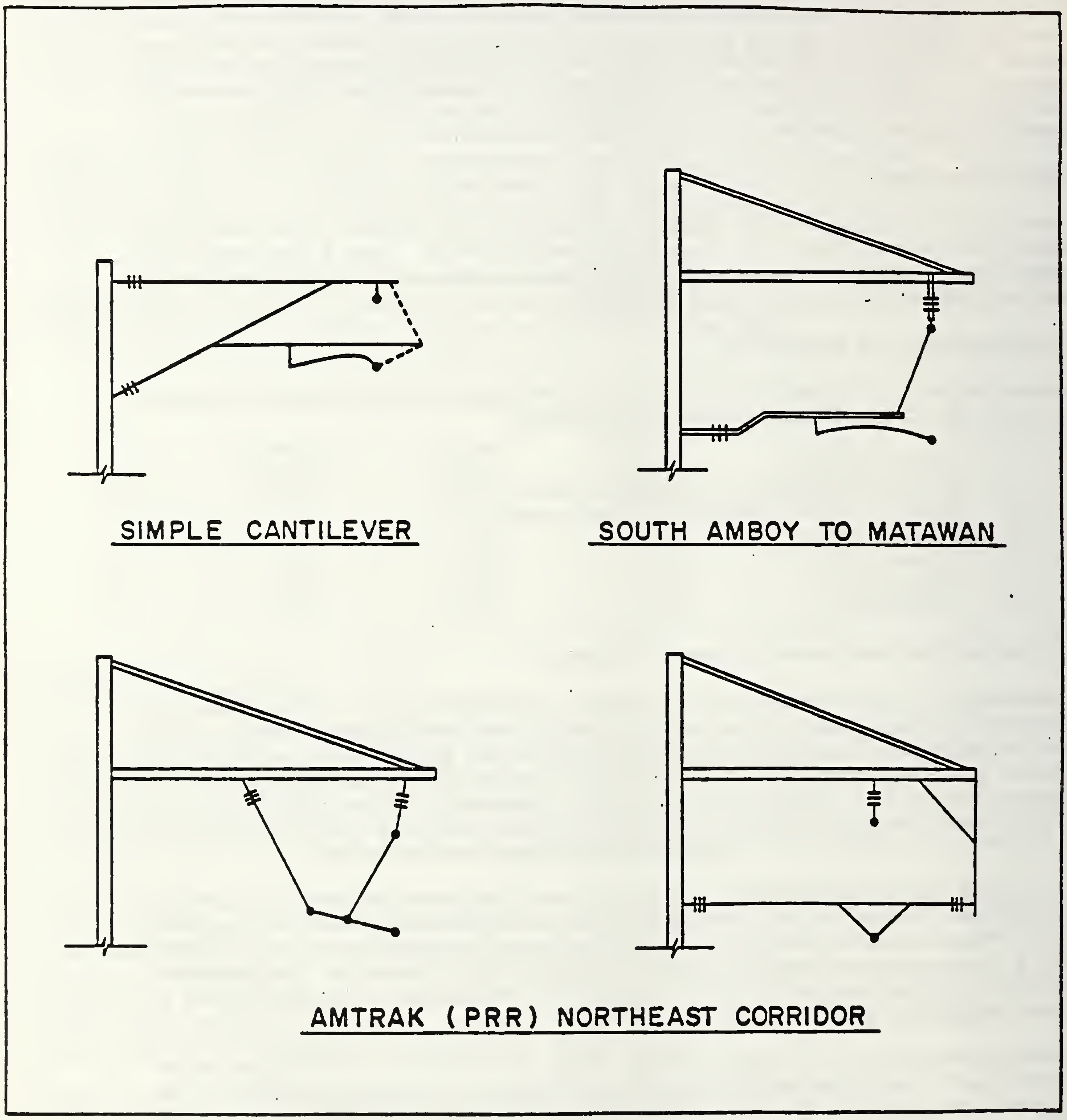
Some of the types considered are shown in Figure 13.

A simple hinged tubular steel cantilever assembly was selected for the NJCL. This type of catenary support is produced by several manufacturers and has been in use for many years in the United States and throughout the rest of the world. Tubular construction provides for easy fabrication, installation and adjustment. The hinged design allows the assembly to swing in response to along track movement of the catenary due to temperature variations. From a structural standpoint, almost no moment is transferred to the pole, thus reducing the pole and foundation strength requirements.

The support assemblies previously used on the South Amboy to Matawan extension and the Northeast Corridor do not lend themselves to support of an AT catenary. To utilize an AT system with these assemblies, the messenger wire would have to be "stitched" with a steel cable that would be supported from a roller attached to the messenger insulator. Stitched catenary is a more expensive form of construction and results in higher maintenance costs.

Another advantage of the hinged cantilever design is aesthetics. The units are simple and have clean lines. Structure heights are reduced since vertical loads are taken by the diagonal tube or strut. The earlier styles of support all require an upward diagonal sag brace to support the main structural member, which increases structure height and costs, and is visually obtrusive, since a larger and more complex structure is created.

In order to maintain the mechanical independence of the catenaries and to accommodate temperature movement of the conductors, light weight portal structures have been chosen for multiple track areas. Hinged cantilevers are attached to a drop bracket



SIMPLE CANTILEVER

SOUTH AMBOY TO MATAWAN

AMTRAK (PRR) NORTHEAST CORRIDOR

SUPPORT AND REGISTRATION STYLES

FIG. 13

suspended from the portal boom to support and register the catenaries over intermediate tracks. Headspan construction was considered for mainline multiple track areas, but was eliminated due to the increased structure height, lack of mechanical independence, and the additional construction and maintenance costs associated with headspans.

Insulation

In order to reduce maintenance costs due to vandalism, non-ceramic insulators are to be installed. Non-ceramic insulators, utilizing a silicon-based shed material, have been used on the Amtrak Northeast Corridor and have an excellent in-use history to date. In addition, non-ceramic insulators are lighter than their porcelain counterparts which is important, not only from a dynamic standpoint for in-span insulation, but also for construction and maintenance. A 100-lb. porcelain insulator string can be replaced with a 10-15 lb. non-ceramic unit. This type of insulator is not affected by diesel exhaust and is self-cleaning, given the relatively wet climate of the East Coast and, consequently, was recommended for this project.

Hangers

Lightweight 3/16" diameter solid stainless steel, non-current carrying hangers were recommended for use in the catenary system, since this type of hanger improves the dynamic movement of the trolley wire. A continuity jumper is to be installed in every span to provide for good current distribution between the messenger and trolley wires.

ANCILLARY WIRES

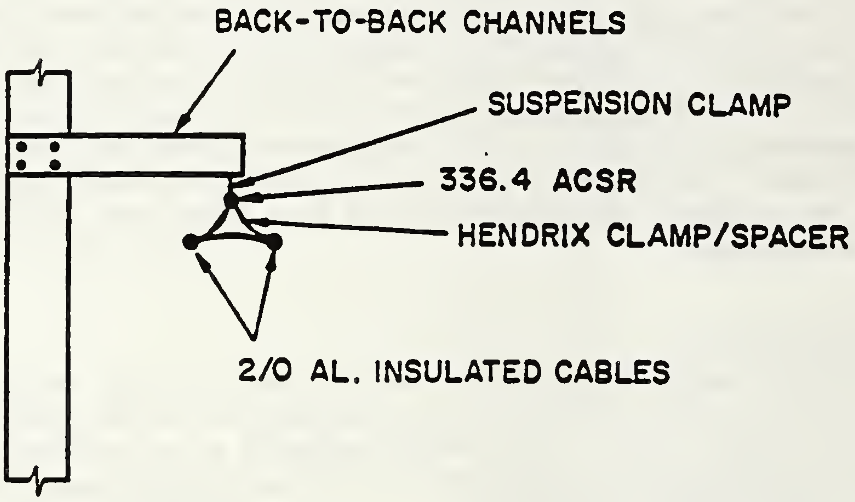
The investigation of ancillary wire size and configuration requirements was based on the electrical criteria developed under the power studies, and required mechanical strengths.

Signal Power Conductors

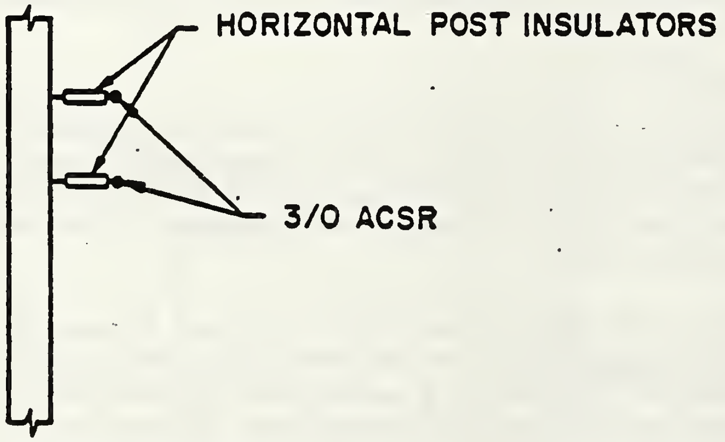
The previous electrification extension from South Amboy to Matawan utilized a bundled insulated conductor configuration for the 6.9 kV, 100 Hz signal power line. The two insulatd 2/0 aluminum conductors were suspended from a 336.4 MCM ACSR messenger cable by Henrix clamp spacers. The ACSR messenger was attached to the structure by back-to-back steel channel outrigger arms.

In an effort to reduce the costs of the signal power system, the use of bare feeders was examined. By utilizing bare 3/0 Pigeon ACSR for the two signal power conductors and supporting them off horizontal post insulators, a savings of approximately 30% was achieved. Additional savings on structure and foundation costs will also be realized due to the elimination of the additional messenger, however, the structural savings were not computed, since the savings in the line itself more than justified the use of the bare conductors. Figure 14 shows the existing configuration and the alternative being used for the new electrification. The two conductors will be in a vertical plane generally, with a distance of two feet betwen the conductors at the support points.

Two separate transmission line circuits, one on each side of the track, are proposed to cover for outages due to catenary maintenance or fault conditions. The step-down transformers at the distributed load points will also be duplicated so that loads can be supplied from either line. It is essential, from a public safety standpoint, that the signaling system be maintained in service at all times and this has prompted NJ Transit decision to have 100% redundancy for the signal power supply distribution system.



SOUTH AMBOY TO MATAWAN



PREFERED ALTERNATIVE

SIGNAL POWER DISTRIBUTION SUPPORT ALTERNATIVES

FIG. 14

Aerial Ground Wire

A 3/0 Pigeon ACSR conductor was selected for the aerial ground wire. This conductor meets the electrical and mechanical requirements for the electrification system with the additional advantage that it is the same conductor as the signal power line, thereby reducing spares inventory requirements, as well as being compatible from a sag, tension and clearance viewpoint.

STRUCTURE ALTERNATIVES

A systems engineering approach was utilized to identify the various structural alternatives to be considered by the NJCL electrification. The poles and foundations were evaluated as coordinated structural units in order to provide for an optimum structure and foundation type.

Study Criteria

Review and study of the route from Aberdeen to Long Branch, excluding the Long Branch Yard area which required special consideration, revealed that the track could be grouped under two primary headings. Approximately 90% of the route is comprised of tangent track, allowing the use of long catenary spans with minimal radial load from the conductors being imposed on the structure; while the remaining 10% of the route is curved track of 2° curve or less. As the curves are very light, the use of tangent chord catenary was selected. Loading diagrams were prepared based on the four catenary configurations, together with the identified ancillary wires.

Pole Alternatives

In selecting poles for analysis, various materials and configurations were assessed with the conclusion that poles made from wide flange steel, tapered tubular steel, prestressed concrete and wood should be investigated. The size and section of each alternative pole, for the four catenary configurations, is shown in Table 3. These sizes were based on maximum span length and loads for each configuration.

For steel and concrete poles, a single track cantilever structure configuration presents the most efficient system to support the catenary and ancillary wires, see Figure 15. Whereas, wood, due to limited axial and bending strength, requires both back-guys and an across-track head guy to provide adequate long-term stability and support for the catenary and ancilliary wires, see Figure 16.

Foundation Alternatives

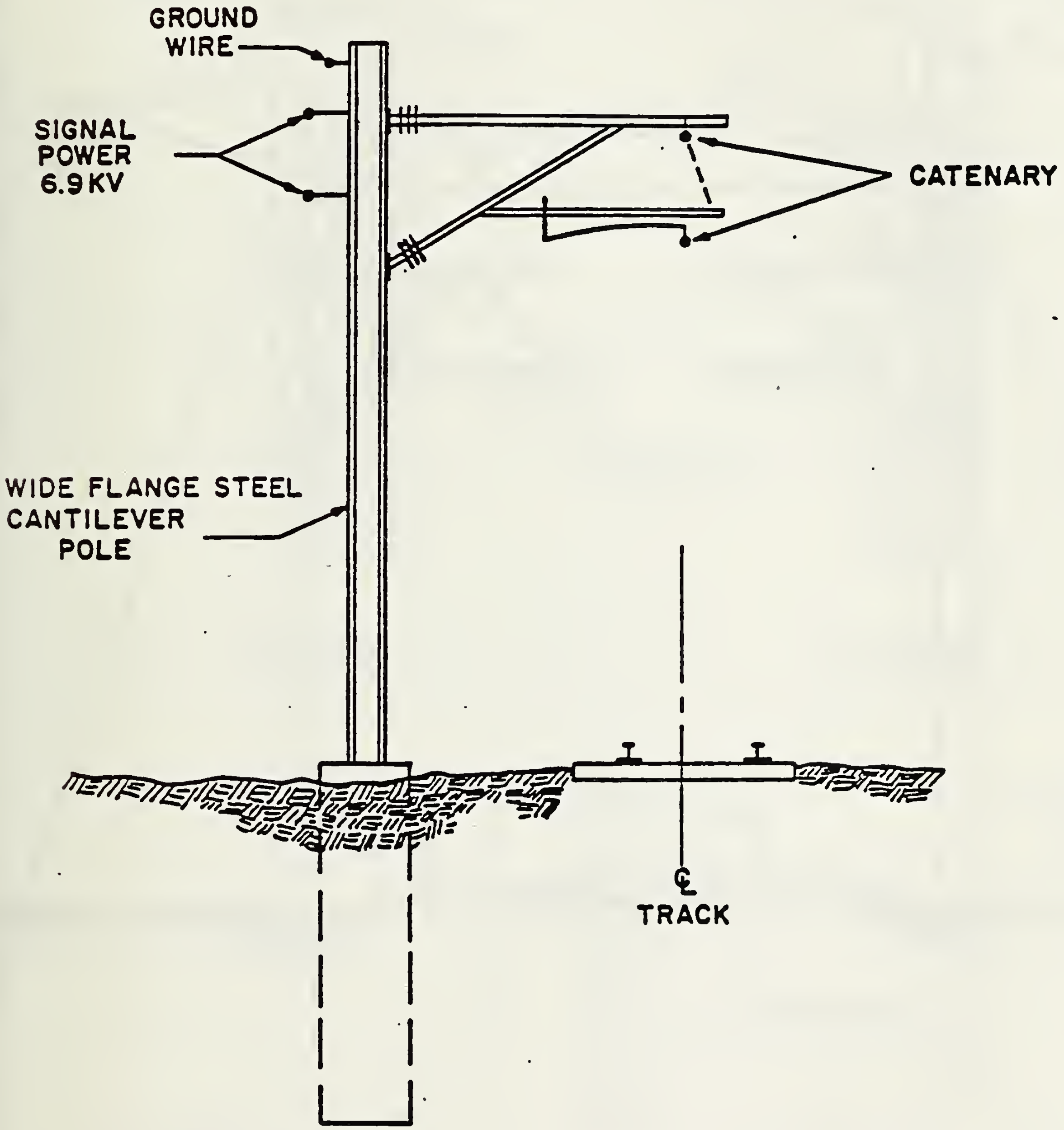
Foundation alternatives chosen for investigation were compatible with the poles and the overall project analysis of good soils with a high water table. Side bearing foundations were investigated in lieu of gravity or spread footing foundations, due to the high cost of the latter type of foundations. Furthermore, the use of gravity foundations was considered likely to increase the amount of track possession time and the overall project duration. The following foundation alternatives were chosen for investigation:

- Bolted base, reinforced concrete pier, see Figure 17, which consists of a concrete cylinder, reinforced with steel bars, with projecting anchor bolts,

POLE ALTERNATIVES

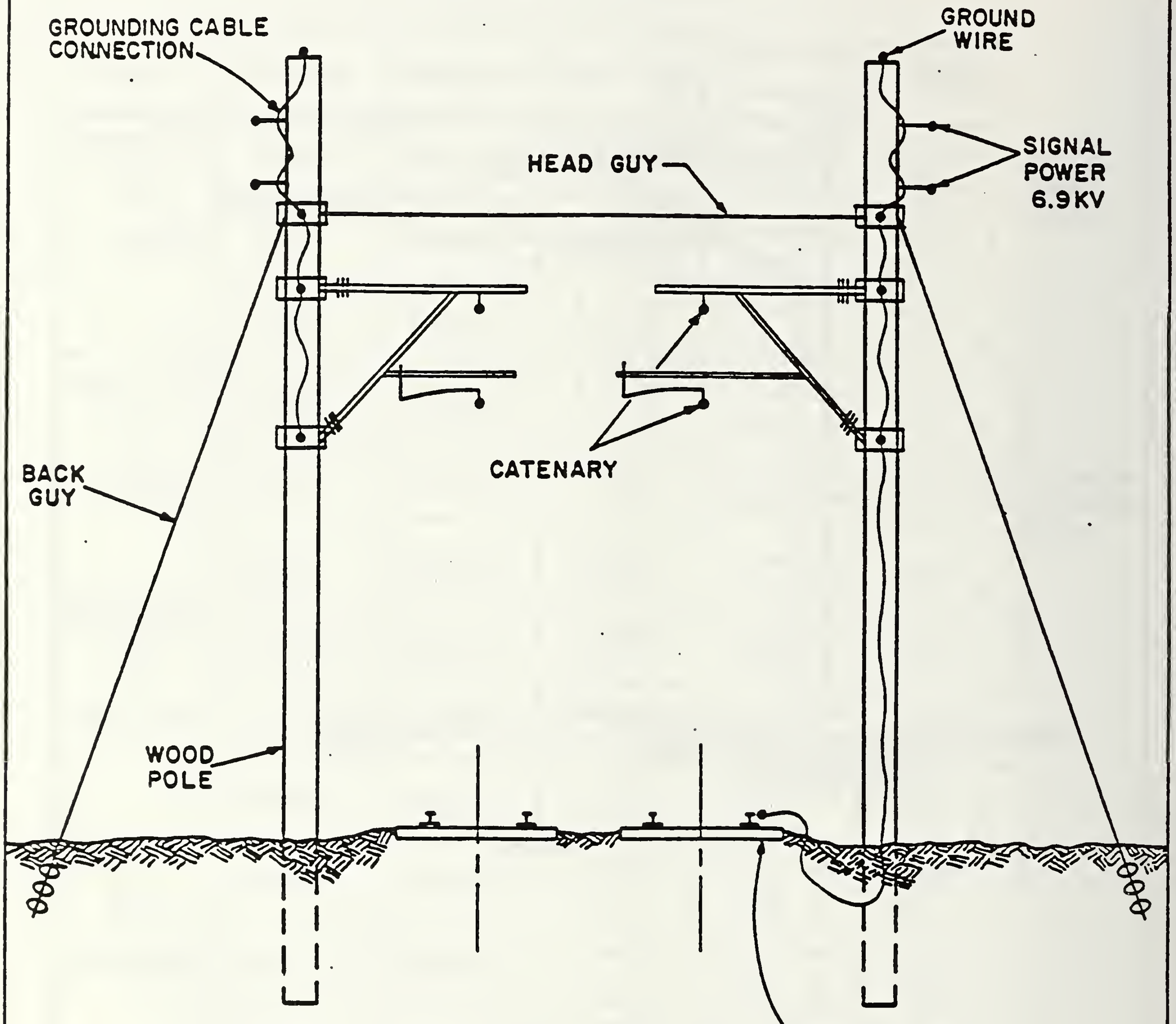
SYSTEM	CONDITION	STEEL WF	STEEL TUBE	PRESTRESS CONCRETE	WOOD
Style 1 AT cu/cu	TANGENT	W8x40	7 GAUGE 13" Ø	8 steel bars 16½" Ø	CLASS 1 14½" Ø
	CURVE	W10x45	3 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 14½" Ø
	SPECIAL	W10x45	3 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 14½" Ø
Style 2 AT cu/brz	TANGENT	W8x40	3 GAUGE 12" Ø	8 steel bars 16½" Ø	CLASS 1 14½" Ø
	CURVE	W10x45	3 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 14½" Ø
	SPECIAL	W10x45	3 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 14½" Ø
Style 3 AT comp/brz	TANGENT	W10x45	3 GAUGE 13" Ø	8 steel bars 16½"Ø	CLASS 1 14½" Ø
	CURVE	W10x45	3 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 14½" Ø
	SPECIAL	W10x45	3 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 14½" Ø
Style 4 FT comp/brz	TANGENT	W8x40	7 GAUGE 13" Ø	8 steel bars 16½" Ø	CLASS 1 16½" Ø
	CURVE	W10x45	0 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 16½" Ø
	SPECIAL	W10x45	0 GAUGE 13" Ø	20 steel bars 16½" Ø	CLASS 1 16½" Ø

TABLE 3



SINGLE TRACK CANTILEVER

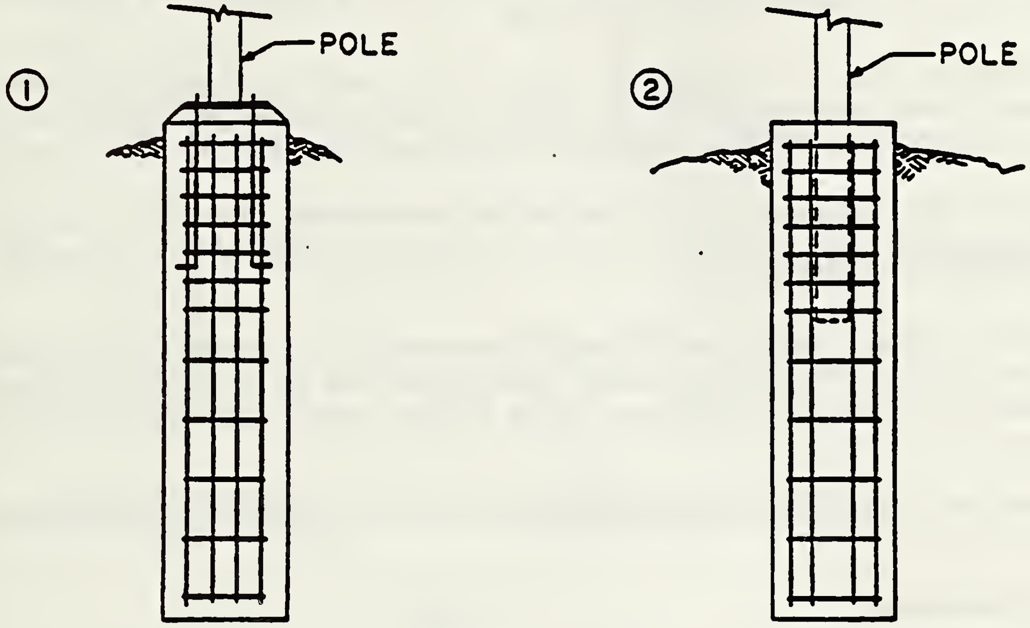
FIG. 15


GROUNDING CABLE CONNECTION
GROUND WIRE
SIGNAL POWER 6.9KV
HEAD GUY
CATENARY
BACK GUY
WOOD POLE
GROUND CONNECTION TO RAIL FOR CROSSBONDING PURPOSES.

WOOD POLE STRUCTURAL ARRANGEMENT

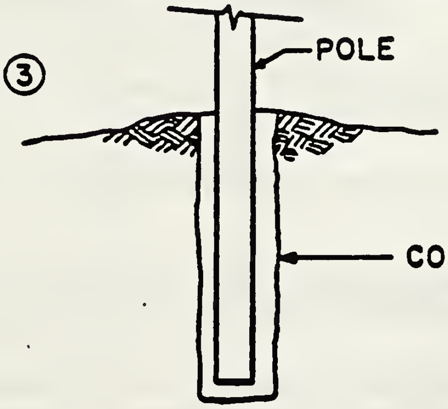
FIG. 16

FOUNDATION ALTERNATIVES



BOLTED

PLANTED



EMBEDDED POLE

FIG. 17

cast-in-place after the hole is augered in the ground.

- Planted reinforced concrete pier, see Figure 17, similar to the bolted base foundation but the anchor bolts are deleted and a core hole is formed as the concrete is cast. Later, the pole is grounted in place.

- Embedded pole, see Figure 17, which consists of an extra length pole with the lower portion used as a foundation. The pole is placed in an augered hole which is then backfilled with concrete.

- Embedded pile, see Figure 18, consists of a steel pile foundation and base plate, placed in an augered hole which is then backfilled with concrete. The bolted base pole is then attached to the foundation pile.

- Driven pile, see Figure 18, is similar to the embedded pile but, instead of an augered hole and concrete backfill, the pile is driven with a vibrating pile driver directly into the soil.

- Driven caisson, see Figure 18, which consists of a round steel caisson that is driven with a vibrating pile driver directly into the soil. The top 6' of soil is excavated, the pole positioned using setting bolts, and then concreted in place.

The size and section of each alternative foundation, for the four catenary configurations, is shown in Table 4.

Discussion of Alternatives

Each of the various pole and foundation combinations was assessed based on experience and engineering judgement in order to limit the number of options to be analyzed in detail. From this assessment, the most technically sound pole and foundation combination for each of the four pole types was chosen. The options were:

- Option 1 - planted, wide flange, steel pole with augered concrete pier foundation

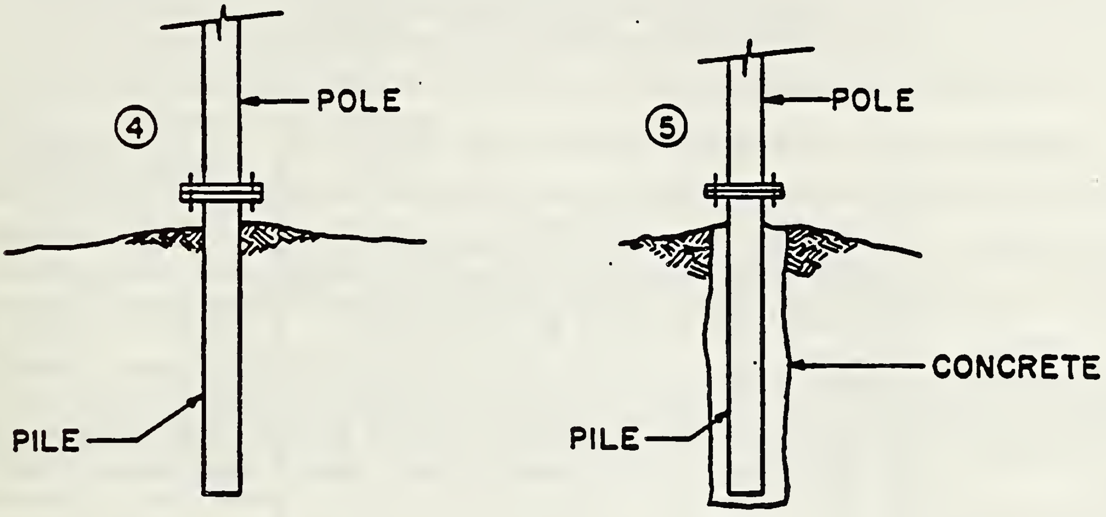
- Option 2 - planted, tapered tubular steel pole with augered concrete pier foundation

- Option 3 - planted, prestressed concrete pole with augered concrete pier foundation

- Option 4 - direct planted wood poles with across-track head guys and double-back guys set in an augered hole and backfilled with concrete.

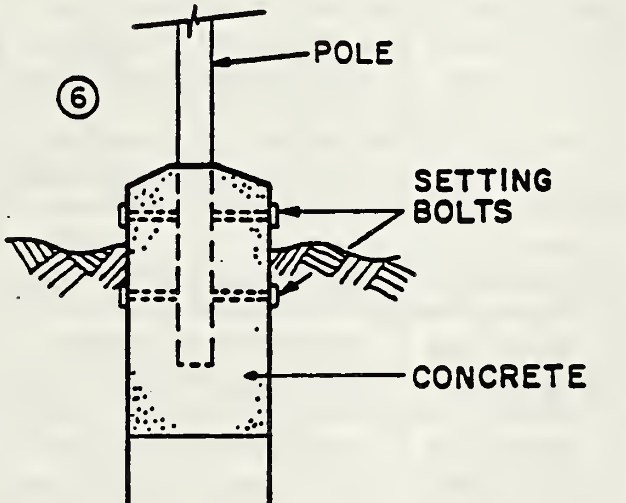
Bolted base poles and foundations were not included in the options on the basis that previous costing exercises had proved that this combination is more costly than planted poles and cored foundations.

A comparison of the four pole foundation options in terms of their effect on the overall catenary system cost revealed no clear choice. However, there are significant technical arguments which influenced the selection of the most desirable option.



DRIVEN PILE

EMBEDDED PILE



DRIVEN CAISSON

FOUNDATION ALTERNATIVES

FIG. 18

FOUNDATION ALTERNATIVES

SYSTEM	CONDITION	HP-PILE	CONCRETE	CAISSON SMALL	CAISSON LARGE	POLE EMBEDDED *	
						SMALL	LARGE
Style 1 AT cu/cu	TANGENT	HP-10x42 21.0' Long	2.5' Ø 17.5' Long	1.5' Ø 20.25' Long	2.5' Ø 18.0' Long	13" Ø 22.0'	17" Ø 20.5'
	CURVE	HP-12x53 21.0' Long	3.0' Ø 17.5' Long	1.75' Ø 20.5' Long	2.5' Ø 18.0' Long	13" Ø 23.5'	17" Ø 22.0'
	SPECIAL	HP-12x53 21.0' Long	3.0' Ø 17.5' Long	1.75' Ø 20.5' Long	2.5' Ø 18.0' Long	13" Ø 23.5'	17" Ø 22.0'
Style 2 AT cu/brz	TANGENT	HP-12x53 21.0' Long	2.5' Ø 18.0' Long	1.5' Ø 21.0' Long	2.5' Ø 18.5' Long	13" Ø 23.5'	17" Ø 21.5'
	CURVE	HP-12x53 21.5' Long	3.0' Ø 17.75' Long	1.75' Ø 21.0' Long	2.5' Ø 18.5' Long	13" Ø 24.0'	17" Ø 22.0'
	SPECIAL	HP-12x53 21.5' Long	3.0' Ø 17.75' Long	1.75' Ø 21.0' Long	2.5' Ø 18.5' Long	13" Ø 24.0'	17" Ø 22.0'
Style 3 AT comp/brz	TANGENT	HP-12x53 21.5' Long	3.0' Ø 17.75' Long	1.5' Ø 21.75' Long	2.5' Ø 18.5' Long	13" Ø 24.0'	17" Ø 21.0'
	CURVE	HP-12x53 22.5' Long	3.0' Ø 18.5' Long	1.75' Ø 21.5' Long	2.5' Ø 19.0' Long	13" Ø 25.0'	17" Ø 23.0'
	SPECIAL	HP-12x53 22.5' Long	3.0' Ø 18.5' Long	1.75' Ø 21.5' Long	2.5' Ø 19.0' Long	13" Ø 25.0'	17" Ø 23.0'
Style 4 FT comp/brz	TANGENT	HP-10x42 21.0' Long	2.5' Ø 17.5' Long	1.5' Ø 20.25' Long	2.5' Ø 18.0' Long	13" Ø 22.0'	17" Ø 20.5'
	CURVE	HP-12x53 22.0' Long	3.0' Ø 18.25' Long	1.75' Ø 21.25' Long	2.5' Ø 19.0' Long	13" Ø 24.5'	17" Ø 22.5'
	SPECIAL	HP-12x53 22.0' Long	3.0' Ø 18.25' Long	1.75' Ø 21.25' Long	2.5' Ø 19.0' Long	13" Ø 24.5'	17" Ø 22.5'

* EXCLUDES WOOD POLES

TABLE 4

Wood poles with back and head guys, Option 4, have several requirements which detract from their desirability:

- Wood poles cannot be used exclusively throughout the route because steel or concrete poles are required at balance weight anchor locations where the axial loads are greatly increased, on high embankments where installation of the back guys becomes extremely difficult and costly, and where right-of-way is restricted and there is insufficient room for back guy installation.
- Additional spare parts inventory due to having both wood, and steel or concrete poles.
- Increased long term maintenance, due to the need for adjustment of guys and cantilevers resulting from increasing permanent pole deflection, or replacement of poles which have failed due to extreme permanent deflection.
- Interconnection of the cantilever brackets and signal power attachments to the ground wire by a separate cable is necessary to achieve the required grounding and bonding. This presents a cluttered appearance on the structure, Figure 16, and adds to the spare parts inventory.
- Cross bonding of ground wires and impedance bonds or neutralizing wires would require an exposed lead or conduit down the face of the pole. This would be susceptible to vandalism.

Concrete poles, Option 3, are similar to wood poles in respect to grounding connections and cross-bonding requirements which detract from their desirability. Steel poles, Options 1 and 2, can be used throughout the route and present a clean profile. A comparison of Options 1 and 2 reveals the following:

- Technically, both satisfy the system requirements.
- Both have essentially the same cost.
- Option 2 presents a cleaner, more pleasing profile since the poles are tapered.
- Option 2 poles are easier to install because alignment of an axis perpendicular to the track is not required since standard tubular poles present a uniform face and have no weak or strong axis.
- Option 1 presents a consistent visual effect with the existing electrification.
- Option 1 uses wide flange poles and maintenance is thereby simplified as pole skates can be used instead of a bucket truck.

This latter point weighed heavily with NJ Transit and the ultimate recommendation was to use wide flange, galvanized steel poles, planted in a coreformed, augered concrete pier foundation. The final design, allowing for site specific analysis of loadings, developed the following pole and foundation combinations:

Poles	Foundations
W10 x 33	2'-9" diameter
W10 x 39	2'-9" diameter
W10 x 49	3'-0" diameter
W10 x 60	3'-0" diameter.

The length of the foundations varies, dependent upon applied loads and soil characteristics, from a minimum of 9'-0" to a maximum of 32'-0".

COST COMPARISONS

In order to develop an accurate evaluation of the comparative costs of the various alternatives, a two-mile section of the route was chosen for evaluation. For the purpose of the evaluation, the system was simplified and single track cantilevers were assumed throughout the section. No multiple track structures, section insulators, signal power transformer stations, switch heater transformers, phase breaks, or other items were included. The portion of the route selected lies roughly between mileposts 9 and 11 and is fairly characteristic of the entire route, since approximately 10% of this section is curved track. For this section of the route, a catenary layout was prepared showing the required structure spacing and positioning for each style of catenary. These layouts were used as baseline documents for estimating and costing each option. The comparative construction costs per single track mile are shown in Table 5.

All costs were based in January 1984 dollars and escalated to the midpoint of construction which was assumed to be April 1986. Escalation was applied at a rate of 5% per year for a composite rate of 11.63%. This preliminary cost estimate included costs for the signal power conductors and supports, but all other related equipment was not included.

SECTIONALIZING

The sectioning for the NJCL between Matawan and Long Branch is shown in Figure 19 and has been designed to provide operating flexibility during catenary outages both for routine maintenance and emergency situations.

Section Breaks

Section breaks in the mainline wires will generally be switched insulated overlaps, often termed "airgaps". The use of insulated overlaps on the mainline is justified by the number of pantographs in use at the 79 mph line speed and is in conformance with existing practice on the NJCL. Mechanical units would require more maintenance for adjustment and replacement of arcing horns and skids.

Electrical continuity through the air breaks will be by means of a normally closed motorized disconnect switch. The disconnect can be opened to isolate a section of catenary for maintenance or emergency purposes. Disconnect switches are remote controlled via a local Remote Terminal Unit (RTU) and the Communications System.

Mechanical section insulators (S.I.) are utilized on crossovers and in Long Branch Yard, and incorporate replaceable insulators, arcing horns and skids to simplify maintenance activities. The mass of the units is to be kept to a minimum for better pantograph interaction.

Phase Breaks

Phase breaks will be installed in the mainline catenaries at substation and switching station locations. The purpose of the phase break is to prevent pantographs from bridging two separate phases of the utility supply network or between 60 Hz and 25 Hz power supply systems. The phase breaks will have a grounded center section to ensure phase isolation. As no phase break negotiation systems are installed in the rolling stock, the phase breaks are required to accommodate hotel loads. Phase breaks, however, cannot tolerate full traction loads on a repetitive basis.

SYSTEM	POLE TYPE / FOUND. TYPE	STEEL WF	STEEL TUBE	PRESTRESSED CONCRETE	WOOD
Style 1 AT cu/cu	CONCRETE PLANTED	241,110	230,626	237,353	
	CONCRETE BOLTED BASE				
	CAISSON				
	HP PILE				
	EMBEDDED				224,736
Style 2 AT cu/brz	CONCRETE PLANTED	251,011	249,172	247,374	
	CONCRETE BOLTED BASE	264,573	256,182		
	CAISSON	259,306	257,468	255,670	
	HP PILE				
	EMBEDDED				236,129
Style 3 AT comp/brz	CONCRETE PLANTED	252,873	250,123	246,687	
	CONCRETE BOLTED BASE				
	CAISSON	261,719	258,959	255,533	
	HP PILE	294,618	280,791		
	EMBEDDED				235,801
Style 4 FT comp/brz	CONCRETE PLANTED	271,138	262,372	267,197	
	CONCRETE BOLTED-BASE				
	CAISSON				
	HP PILE				
	EMBEDDED				

NOTE: COSTS ARE EXPRESSED AS 1984 DOLLARS PER SINGLE TRACK MILE, INCLUDING SIGNAL POWER DISTRIBUTION

TABLE 5

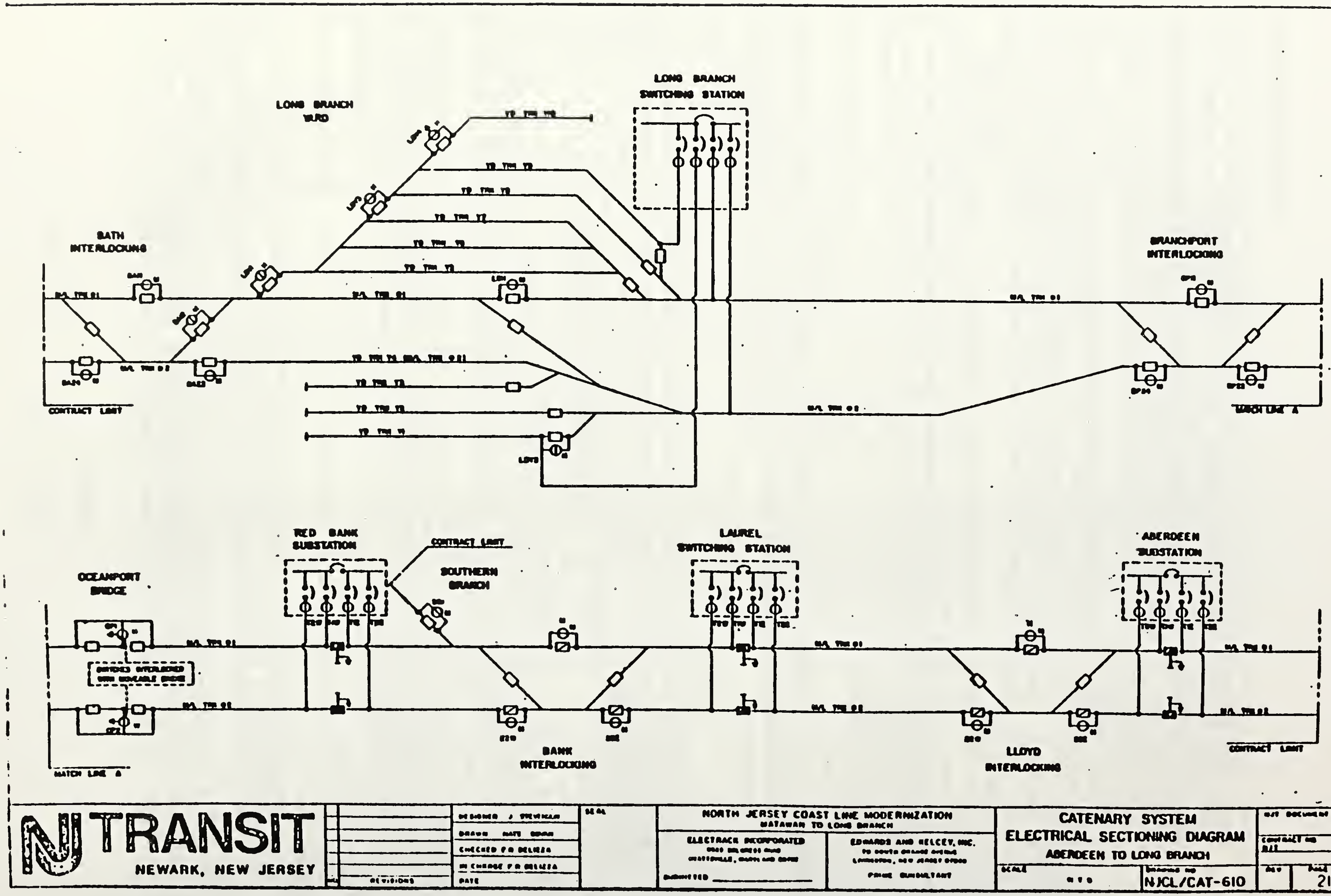

LONG BRANCH YARD
LONG BRANCH SWITCHING STATION
BATH INTERLOCKING
BRANCHPORT INTERLOCKING
CONTRACT LIMIT
MATCH LINE A
OCEANPORT BRIDGE
RED BANK SUBSTATION
CONTRACT LIMIT
SOUTHERN BRANCH
LAUREL SWITCHING STATION
ABERDEEN SUBSTATION
BANK INTERLOCKING
LLOYD INTERLOCKING
MATCH LINE A
CONTRACT LIMIT
NJ TRANSIT
NEWARK, NEW JERSEY
REVISIONS
NORTH JERSEY COAST LINE MODERNIZATION
MATAWAN TO LONG BRANCH
ELECTRACK INCORPORATED
EDWARDS AND KELCEY, INC.
CATENARY SYSTEM
ELECTRICAL SECTIONING DIAGRAM
ABERDEEN TO LONG BRANCH
NJCL/CAT-610

FIG. 19

Motorized Disconnect Switches

Motorized disconnect switches will be installed at all mainline sectionalizing locations and are to be suitable for operation at both 12.5 and 25 kV. The disconnect switches will not be load breaking, and are rated for 1000 A continuous operation. Motor operators will be 125 V DC, which will be supplied from the substation or switching station batteries at phase break locations, but, at interlockings, the DC supply is to be obtained via an independent tap from the signal power supply system and a rectifier unit.

LONG BRANCH YARD

For the purpose of catenary design, the Long Branch Yard complex extends from the proposed universal crossovers on the Matawan side of the Long Branch curve, through the curve, station and yard areas, to approximately 1,200 feet beyond the proposed universal crossovers on the Bay Head side of the complex.

Catenary

Style 4 FT catenary has been used throughout the yard and was chosen for several reasons. It is compatible with the existing and proposed mainline catenaries, but long span lengths are not required due to the curvature on the mainline and the geometry of the yard layout. Furthermore, the low speeds in this area eliminate the need for the dynamic performance advantages of constant tensioned equipment.

Structure Types

The predominant type of structure to be installed in the Yard area is a long span portal with a lightweight trusportal boom, some of which are compound three-leg portals. In addition, a number of pull-off poles and single track cantilevers are also required. Considerable coordination has been undertaken with the civil and architectural designs to conform placement of structures and foundations to avoid impacting buried utilities, sound barrier walls, pedestrian circulation in parking areas, walkways and station platforms.

Sectionalizing and Feeding

The sectionalizing arrangement for the yard has been designed to accommodate operational requirements, and back feeding from the main lines has been provided to keep the yard in service during switching station maintenance or repair. In order to keep the appearance of the yard wiring as uncluttered as possible, all feeders including signal power are to be routed underground to the switching station. Only disconnect switches and taps will be pole mounted.

DRAWING FORMAT

The drawing formats chosen for the NJCL have been developed to produce both design and construction economies by reducing the overall amount of documentation required. A sample layout/allocation schedule is shown in Figure 20. This type of schedule has been used previously on other electrification schemes designed by the authors and covers both material allocation and installation activities.

This system utilizes assembly level material allocation; the sample provided demonstrates how the assembly drawing, Figure 21, section of the final design package is cross-referenced to site requirements to permit ready assessment of total quantities for

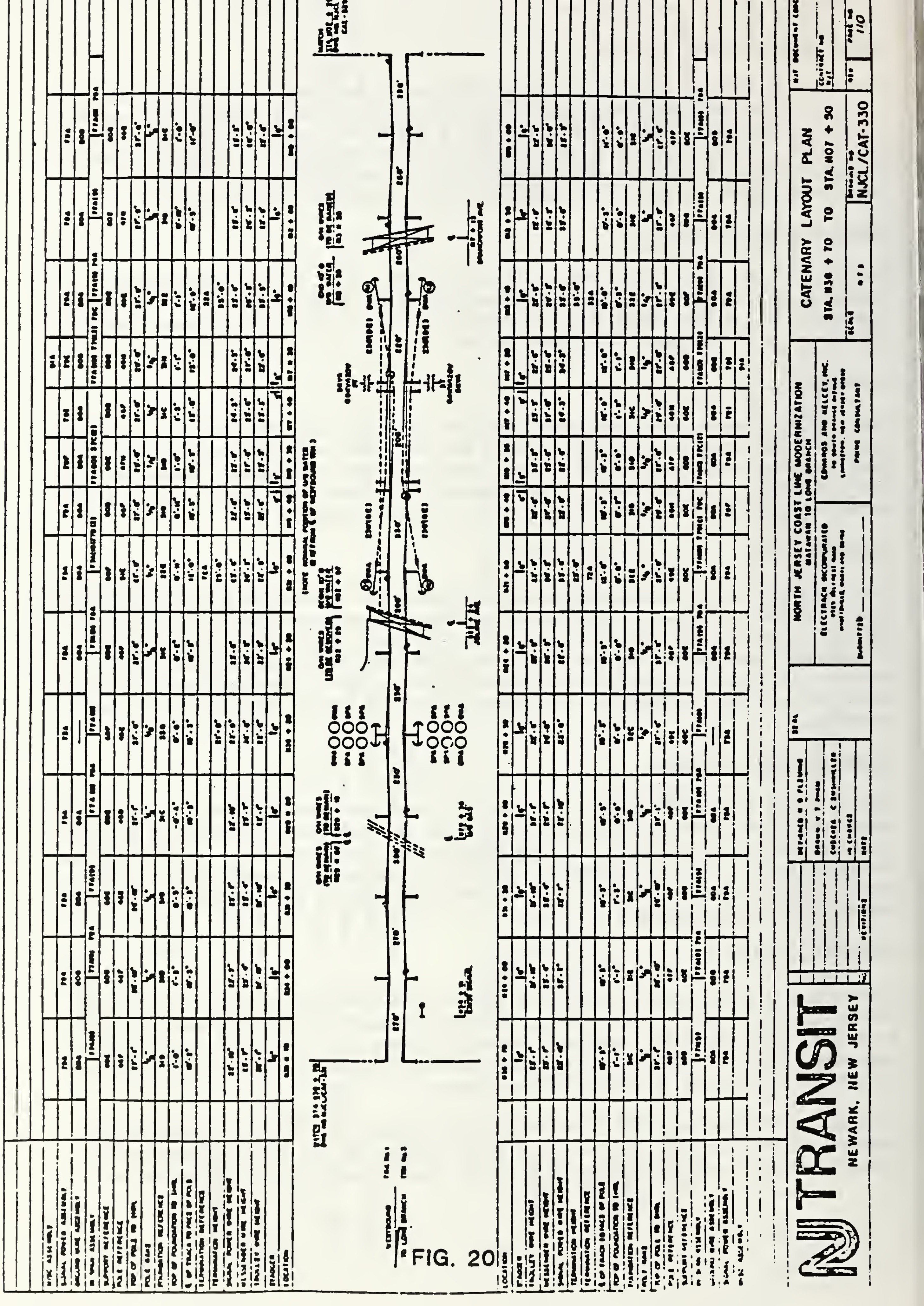


FIG. 20

NORTH JERSEY COAST LINE MODERNIZATION
MATAWAN TO LONG BRANCH
CATENARY LAYOUT PLAN
STA. 830 + 70 TO STA. 407 + 30
NJCL/CAT-330
NJ TRANSIT
NEWARK, NEW JERSEY
ELECTRACK INCORPORATED

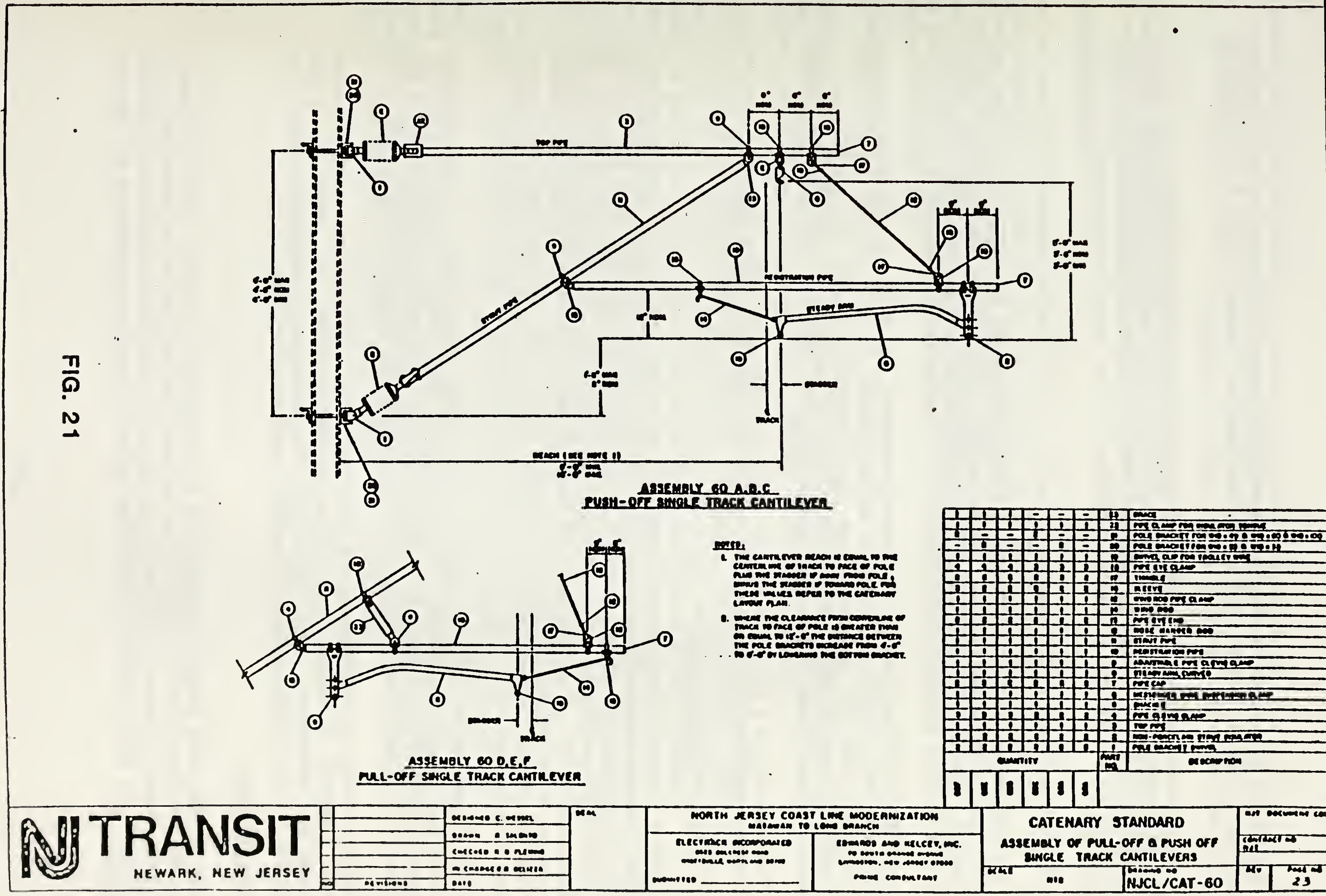


FIG. 21

NOTES:

1. THE CANTILEVER REACH IS EQUAL TO THE CENTERLINE OF TRACK TO FACE OF POLE PLUS THE STAGGER IF AWAY FROM POLE, MINUS THE STAGGER IF TOWARD POLE. FOR THESE VALUES REFER TO THE CATENARY LAYOUT PLAN.

2. WHERE THE CLEARANCE FROM CENTERLINE OF TRACK TO FACE OF POLE IS GREATER THAN OR EQUAL TO [illegible] THE DISTANCE BETWEEN THE POLE BRACKETS INCREASE FROM [illegible] TO [illegible] BY LOWERING THE BOTTOM BRACKET.

preparation of a bill of materials. Assembly drawings are prepared to a level of detail sufficient to allow suppliers to bid on the complete catenary system. References to proprietary items are avoided to the greatest extent possible.

In addition to materials allocation, this document also provides installation dimensioning for standard poles, foundations, and support assemblies. As-built modifications can be easily incorporated, thereby furnishing a convenient and comprehensive inventory to NJ Transit, for record and maintenance purposes, of the material requirements at each location.

EXISTING ASSEMBLIES

The proposed electrification system represents a completely new style of catenary to the NJ Transit electrified system. The existing electrification consists of former Pennsylvania Railroad and converted Erie-Lackawanna Railroad catenaries on the older segments, and a second generation updated PRR catenary on the newer extensions.

The intent of the new design is to obtain the catenary components from a single supplier, thus ensuring complete uniformity of all components for form, fit and function. This being the case, the assemblies have been designed to avoid the specification of proprietary designs, and the contract documents prepared in the form of outline assembly drawings and performance specifications.

The new design is a flexible, automatic tensioned catenary in which basic items such as supports, registrations and hangers are different to the existing assemblies.

CATENARY DESIGN BASIS

Analysis of the many options identified resulted in adoption of a recommendation that Style 3 catenary be utilized in conjunction with wide-flange steel poles and augered, cored, concrete pier foundations. While this was not the cheapest alternative, it will provide NJ Transit with a technically preferred system at a reasonable first cost and low maintenance cost. The high tension pre-sagged trolley wire will provide good dynamic response to the multiple pantograph operations on the route, and the longer span lengths allow for fewer structures, thereby reducing the number of registrations and ancillary wire attachments.

This catenary is also the most aesthetic of the systems evaluated. The reduced system depth and longer span lengths will combine to reduce the visual impact on the surrounding countryside and will tend to reduce the tunnel effect perceived when riding in the front of the train or looking down the tracks from a station or grade crossing.

The wide-flange steel poles present a good strength to weight ratio, are readily available from a number of suppliers, are simple and easy to install, and provide for simple equipment attachment. This type of pole has gained public acceptance, since it is similar to those already utilized in the NJCL existing electrification.

CONCLUSION

Most of the detail design is scheduled to be completed by mid-1985. Major equipment for the substations and switching stations has been specified and will be purchased by NJ Transit ahead of time and supplied at no cost to the construction contractor. This will eliminate any undue delay due to the longer periods required to manufacture and test the equipment.

The generic design of the catenary system will permit bidding by any competent catenary hardware manufacturer whose responsibility it will be to ensure form and fit of all the components. This design basis will assure competitive bidding for the catenary system.

NJ Transit plans to have all systems operating on schedule and is giving then the fullest attention. So far, the project is meeting major milestones and there is every expectation that it will meet the target date of revenue service by early 1988.

ACKNOWLEDGEMENT

We wish to thank EMJ/Electrack for permitting us to present this paper. We also wish to thank our colleagues, in particular Mr. P. L. Shaw, Mr. J. D. Henderson and Mr. D. McAlpine, for reviewing the paper for continuity and format; and Dr. T. A. Kneschke and Mr. F. R. DeLizza for providing input to the Power Study and Catenary Alternatives sections of the paper, respectively. We would also like to thank JCP&L Co.; Edwards & Kelcey Inc., and NJ Transit in particular the Project Director, Bob Keith for their approval to publish this paper.

BIOGRAPHICAL SKETCHES

This paper has been prepared by Michael N. Lewis and M. Ajmal Khan, of EMJ/Electrack Inc., the design subconsultant for all aspects of electrification of the North Jersey Coast Line. Edwards and Kelcey, Inc., Livingston, New Jersey, is the prime consultant.

Mike Lewis is the Electrack Project Manager and has 23 years experience involving electric traction power design, procurement and installation, on railroad and rapid transit electrification projects in the United States, Great Britain, Pakistan and Taiwan. In addition to the North Jersey Coast Line, his project management duties currently cover the Century Freeway LRT in Los Angeles and the West Chester Branch Electric Traction Improvements in Philadelphia; and, in the past, have covered such projects as the San Diego East Urban Line and San Diego South Line and Buffalo LRRT Projects. In Britain, Pakistan and Taiwan, he has supervised the procurement and installation of catenary systems, after involvement in the design phases of the projects.

Ajmal Khan is the Principal Power Engineer responsible for preparation of the electrical design package. He has over 19 years of experience in the electric power study, design, construction, operation, maintenance and construction management of utility, industrial and traction power systems. His 10 years with a utility company and 9 years in the consulting profession combine both the field and design experience necessary for a comprehensive system design of the type needed for this project. In the United States, he has prepared power system designs for the Northeast Corridor, San Diego LRT South Line, Buffalo LRRT, and Wayne Junction rehabilitation work for SEPTA.

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510/419-6000 Fax 510/419-5355

①

April 4, 1996

Mr. Alan Saunders
Pacific Gas & Electric Co.
123 Mission Street
San Francisco, CA 941777
P.O Box 770000
Mail Code H28B

Subject: **CalTrain Electrification Project - Power Requirements**

Dear Alan:

We have prepared this letter to provide you with the specific information you requested in your phone message to me today, April 4, 1996.

A. Project background

CalTrain, a commuter rail system presently uses diesel-locomotive and is operating between San Francisco and San Jose/Gilroy. Alternative studies of investigating the locomotive propulsion system options are underway for the extension of the service into downtown San Francisco. Previous studies have recommended to use 25 kV ac single phase, 60 HZ power supply via overhead catenary system. The power system and economic studies are considering various options of the electrification system. They are a) diesel & electric dual mode option; existing diesel locomotives to be modified to run on a 25 kV ac single phase electric power when train is in downtown San Francisco b) full electrification option considers the entire route approximately 78.6 miles to use 25 kV ac single phase power distribution system.

B. Response to your specific questions

1. Who is the sponsoring agency ?

   Peninsula Corridor Joint Powers Board

2. Timing when the project will be built

   It is planned to commence the construction of the extension in year 2000-2005.

3. What information is needed from PG&E

②

Power system studies have outlined preliminary power requirements for both options of a) full electrification system and b) electrification of the downtown extension only using 25 kV single phase ac power supply from PG&E. Preliminary locations and capacity of the traction power substations along the right of way have been identified as shown in the attached sketch SK-2. We would like to discuss the technical information with PG&E to confirm the power supply tap locations for these substations and other interface requirements such as:

- PG&E existing or planned primary power distribution system and supply voltage rating to each tentative substation location.
- Any modifications to PG&E primary power supply system to a particular substation location that will impact CalTrain project other than normal supply charges.
- Limitations on power factor, voltage and harmonic distortion etc. at the primary power supply location.

We would like to meet with your technical people the week of April 8, 1996. Your cooperation on this is appreciated. You can contact me at Tel. No. (510) 419 - 6448.

Dev Paul Dev Paul
Principal Electrical Engineer

Enclosures

cc: Dave Minister
Rey Belardo
File

P:\65928\PG&E

25kV AC
SYSTEM ELECTRIFICATION

Attachment 2

CALTRAIN ELECTRIFICATION PROJECT

ESTIMATED MAXIMUM PEAK HOUR (KW) DEMAND CALCULATION

CALCULATION NO. 1

ESTIMATED VALUE OF POWER DEMAND BASED UPON ENERGY CONSUMPTION (kWH/CAR - MILE), TRAIN OPERATING SCHEDULE AND DISTANCE

Approximate distance from San-Francisco to Gilroy = 78.6 miles

During peak hour operation total of 17 trains are considered in the system. Eight 7-car trains and nine 5-car trains (total of 101 cars) on both tracks. The energy consumption for a 4-car train is indicated as 47 kWH/mile in MK report dated Oct. 1992. Train travel time between San Francisco to Gilroy is in the order of 6770 seconds (approximately 1.88 hours). Thus the train headway considering seventeen trains in the peak hour will be in the order of 6.6 minutes (1.88 x 60 / 17), use 6.5 minute for this calculation..

kWH/ Car - mile = A

Therefore :

kW= A x (Car - miles)/ Hour

Cars/ Hour = (60/ Headway in minutes) x (Cars/ Train)

Car - miles/Hour = 2 x 78.6 miles x (60/ Headway in minutes) x (Cars/ Train)

Car - miles/Hour = 2 x 78.6 x (60/6.5) x 6 = 8706

Considering A = 11.75

kW = 11.75 x 8706 = 102,295

Please note that each train is considered to be six car train to compute Cars/hour in operation. The calculated value of kW power requirement is in the order of 102 MW. If the headway is considered to be six minutes then required power will become 111 MW. For six car train the specific value of energy consumption will be slightly greater than the value of 11.75 used in the above calculation.

CALCULATION NO 2

CALTRAIN ELECTRIFICATION PROJECT
25 kV SINGLE PHASE POWER SUPPLY SYSTEM

1. General

During peak hour operation the maximum of seventeen (17) trains are expected in the system.Eight trains will consist of 7-car train and nine trains will consist of 5-car trains . In addition it is envisioned that an express train consisting of 10-car trains requiring double locomotives will be operated in the future. Train storage yard near 16th street and Owens is sized for at least eight (8) trains capacity. Propulsion power requirements for the electrification system indicated in this analysis are based upon the ABB ALP-4 locomotive. For maximum expected RMS power requirement it is assumed that all trains are 7-car trains.

2. Maximum Power System Demand - Main line

Consider 17 trains during peak hour operation including say two express trainsfor future. Express train will consist of two locomotives and ten car trains; thus requiring more power demand as compared to a normal seven car train.

RMS current of a 7-car train with ALP-44 electric locomotive is in the order of 242 amps without the Hotel power. Based upon the Hotel power estimated by ABB of 31 amperes for the 7- car train the maximum estimated RMS current at 25 kV ac will become 273 amps.

Based upon the above considerations the RMS current for the express train will be in the order of 395 amps [(10/7 x 242 + 10/7 (31.0)] .

$$\mathrm{KVA} := \mathrm{amp}\cdot\mathrm{KV}$$

$$\mathrm{POWER} := 25\cdot\mathrm{KV}\cdot(17\cdot 242 + 2\cdot 395)\cdot\mathrm{amp}$$

$$\mathrm{POWER} = 1.226\cdot 10^{5}\ \cdot\mathrm{KVA}$$

This calculation indicates that the maximum power demand will be near 122.6 MVA which will be some what lesser for the seven car train operation rather than the eight car train operation.

To meet abve estimated maximum traction power demand; five (5) Traction Power Substations (TPSS) each with rating in the order of 20/26.6/35.4 MVA are required. Under abnormal system operation when any one of the TPSS is out of service the remaining four TPSS's will not be overloaded to meet the power requirement without any reduction in train propulsion power requirement.

3. Yard near 16th and Owens street - Average demand

Trains in the yard may be ready to move thus driving auxiliary power only, except one train moving out of the yard may be running at 20 to 25 MPH speed. Thus the expected power for the yard system will be as follows.

$I_{aux} := 31 \cdot amp$	One 7-car train auxiliary power current at 25 kV catenary voltage
$I_{moving} := 200 \cdot amp$	One 7-car train moving out of the yard at 20MPH speed current at 25 kV .
$I_{yard} := 7 \cdot I_{aux} + I_{moving}$	Total expected maximum current for the trains in the yard at 25 kV catenary voltage

$$I_{yard} = 417 \cdot amp$$

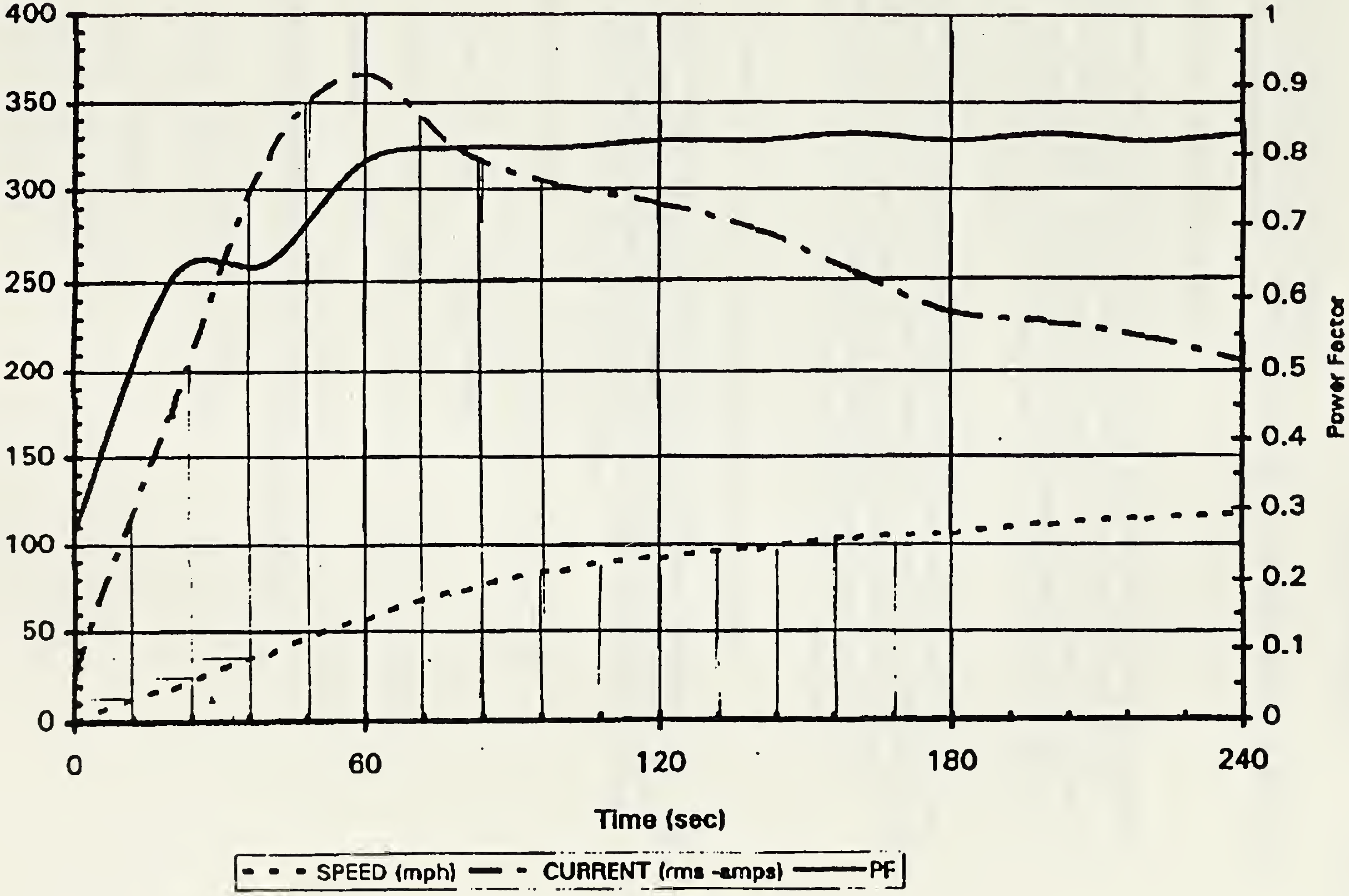
$$KVA := amp \cdot KV$$

$$KVA_{yard} := I_{yard} \cdot 25 \cdot KV$$

$$KVA_{yard} = 1.043 \cdot 10^{4} \cdot KVA$$

Main line 25 kV power will be used to power the yard tracks as required.

AEM-7 Performance Data
25 kV/60 Hz, 8 car train



CALCULATION NO. 3

CALTRAIN ELECTRIFICATION PROJECT
INDIVIDUAL TRACTION POWER SUBSTATION MAXIMUM 5 SECONDS AND 15 MINUTES DEMAND LOAD ESTIMATION

A. Basis of Traction Power Demand load

During peak hour train operation system there will be seventeen (17) trains in the system. Eight 7-car trains and the nine 5-car trains (total of 101 cars) on both inbound and outbound tracks. During morning peak hour operation inbound trains to San Francisco are more than the outbound trains to San Jose. During evening peak hour operation the outbound trains to San Jose will be more than the inbound trains to San Francisco as required by traffic schedule.

Considering five traction power substations under normal operation, each traction power substation will be providing power to say maximum of four trains. During abnormal system operation when one of the traction power substation is out of service, the adjacent substation will service the maximum of say six trains, except the outage of the end substations where the next substation may be supplying power to seven trains.

B. Estimated power demand of each traction power substation is as follows:

Refer to attached AEM-7/ALP-44 electric locomotive performance data Figure 1. For eight car train the auxiliary power (HEP) is considered in the order of 35 A and will be used in addition to the traction current indicated in the curve. Based upon this data train currents during acceleration and running periods are as follows:

1. Train acceleration current (maximum instantaneous) for 5 sec interval

$$I_{5sec} := 365 \cdot amp \qquad I_{HEP} := 35 \cdot amp$$

$$I_{max5sec} := I_{5sec} + I_{HEP}$$

$$I_{max5sec} = 400 \cdot amp$$

2. Maximum Average RMS train current for 1 minute time interval

$$I_{1min} := \sqrt{\frac{350^2 + 370^2 + 340^2 + 315^2}{4}} \cdot amp$$

$$I_{1min} = 344.32 \cdot amp$$

$$I_{max1} := I_{1min} + I_{HEP}$$

$$I_{max1} = 379.32 \cdot amp$$

3. Max. Average RMS train current for 4 minutes interval

$A := 115^2 + 200^2 + 300^2 + 350^2 + 370^2 + 340^2 + 315^2 + 305^2 + 300^2 + 290^2$

$B := 280^2 + 275^2 + 260^2 + 240^2 + 230^2 + 230^2 + 230^2 + 220^2 + 210^2 + 205^2$

$$I_{4min} := \sqrt{\frac{A+B}{20}} \cdot amp$$

$I_{4min} = 269.91 \cdot amp$

$I_{max4} := I_{4min} + I_{HEP}$

$I_{max4} = 304.91 \cdot amp$

4. Max. Average RMS train current for 15 minutes

$$I_{15min} := \sqrt{\frac{269.91^2 + 200^2 + 200^2 + 195^2 + 190^2 + 185^2 + 185^2 + 185^2}{8}} \cdot amp$$

$I_{15min} = 202.994 \cdot amp$

C. Substation power demand

1. Normal operation

a) Max. 5 seconds power demand based upon the train currents as follows:

$I_{max5sec} = 400 \cdot amp$

$I_{max1} = 379.32 \cdot amp$

$I_{2trains} := 2 \cdot I_{15min}$

$I_{2trains} = 405.987 \cdot amp$

$I_{max} := I_{max5sec} + I_{max1} + I_{2trains}$ $I_{max} = 1.185 \cdot 10^3 \cdot amp$

$\mathrm{MVA} := \mathrm{amp} \cdot \mathrm{KV} \cdot 10^3$

$D_{5sec} := I_{max} \cdot 25 \cdot \mathrm{KV}$

$D_{5sec} = 29.633 \cdot \mathrm{MVA}$

b. Maximum 15 minutes power demand of a substation based upon the requirement of four trains in different modes of operation with currents indicated in above paragraphs

$$I_{rms15} := \sqrt{\frac{\frac{5}{60} \cdot 400^2 + 379.32^2 + \left(4 \cdot 304.91^2\right) + 15 \cdot 203.0^2}{15}} \cdot \mathrm{amp}$$

$I_{rms15} = 276.554 \cdot \mathrm{amp}$

$D_{15min} := 4 \cdot I_{rms15} \cdot 25 \cdot \mathrm{KV}$

$D_{15min} = 27.655 \cdot \mathrm{MVA}$

2. Abnormal system operation

a. Max. 5 sec instantaneous power demand, considering five trains load on one substation, with trains in different modes drawing different currents with combination as follows:

$I_5 := I_{max5sec} + 2 \cdot I_{max1} + 3 \cdot I_{15min}$

$I_5 = 1.768 \cdot 10^3 \cdot \mathrm{amp}$

$D_{5secab} := I_5 \cdot 25 \cdot \mathrm{KV}$

$D_{5secab} = 44.191 \cdot \mathrm{MVA}$

b. Max. 15 minutes power demand of a substation with five trains load in different modes of operation with combination as follows:

$D_{15minab} := 6 \cdot I_{rms15} \cdot 25 \cdot \mathrm{KV}$

$D_{15minab} = 41.483 \cdot \mathrm{MVA}$

Please note that the above calculated values instantaneous 5seconds and average 15 minutes demand loadings of a particular substation are based upon 8 car trains and these values will reduce with smaller train consist.

The values indicated in the attached Table 1 are estmated loading of each substation under normal and abnormal system operation. System is considered normal when all substations are in operation and considered abnormal when any one of the substation is out of service and the adjacent substations supply the additional load of trains in the outage substation area. Present system is considered as 4-car trains with seven trains per hour and the future system is considered as five car trains with ten trains per hour as shown in the Attached Rail Service Schedule Parameters

SUBSTATION LOADING IN MVA DURING PEAK HOUR TRAIN OPERATION SYSTEM				
TPSS #	Normal		Abnormal	
	Present	Future	Present	Future
1	10.2	18.2	14.5	25.6
2	9.6	16.9	16.6	29.6
3	14.2	25.2	20.9	37.3
4	9.1	16.2	18	31.8
5	10.8	18.2	13.7	23

TABLE:1

4-car, 7/H
5-car, 10/H

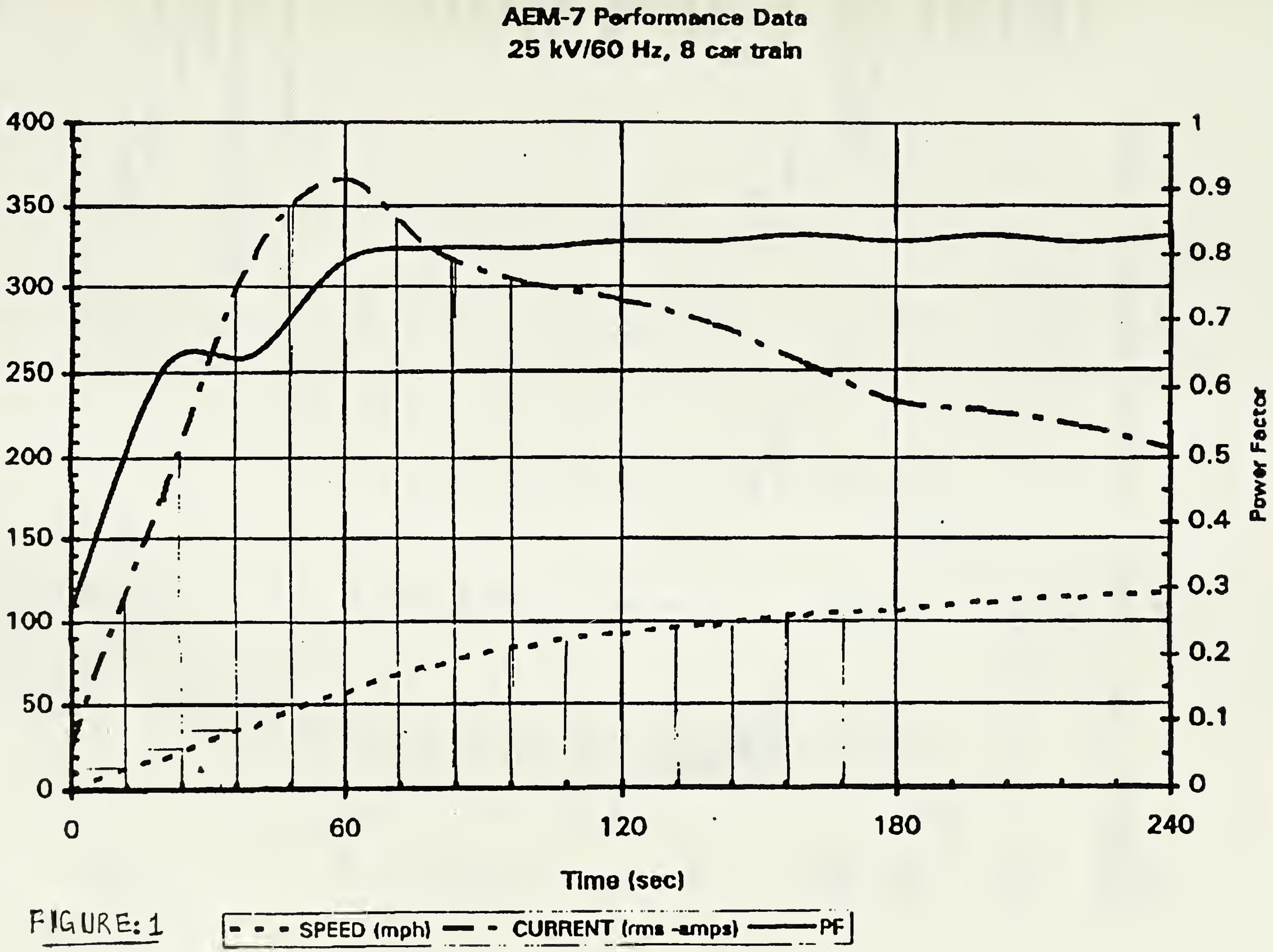

AEM-7 Performance Data
25 kV/60 Hz, 8 car train
400
350
300
250
200
150
100
50
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Power Factor
0
60
120
180
240
Time (sec)
SPEED (mph)
CURRENT (rms -amps)
PF

FIGURE: 1

Caltrain SF Downtown Extension Project DEIS/R
Rail Service Schedule Parameters
January 19, 1996

PRESENT

FUTURE

		Today	60 ~~Trains~~ cars	Proposed	72 ~~Trains~~ cars	Proposed	86 ~~Trains~~ cars
4 car trains			12		10		
5 car trains			3		3		
6 car trains					2		8
7 car trains							
8 car trains							
9 car trains							
10 car trains							10
Total Cars for Service			63		67		148
Trainsets for Service			15 +1		15		18
		Trains Per Hour		*Trains Per Hour*		*Trains Per Hour*	
AM Peak							
	Inbound	7	12	7	12	10	15
	Outbound	4	8	4	8	4	8
PM Peak							
	Inbound	3	7	3	7	4	8
	Outbound	6	11	6	11	10	15
Off Peak							
Morning	Inbound	1	1	1	1	1	1
	Outbound	1	1	1	1	1	1
Midday	Inbound	1	7	2	13	2	13
	Outbound	1	7	2	13	2	13
Evening	Inbound	1	3	1	3	2	6
	Outbound	1	3	1	3	2	6
Total			60		72		86

Distribution of Equipment (Trainsets)

OffPeak Service Equipment Requirements				
Hourly Service		3		
Half-hourly Service			6	6
Midday Storage	San Jose	5	5	5
	San Francisco	7 ✓	4	7
Total		15	15	18
Overnight Storage	San Jose	11 ✓	11	14
	San Francisco	4 ✓	4	4
		15	15	18

CALTRAIN ELECTRIFICATION PROJECT
SUBSTATION SPACING ANALYSIS
AND TRAIN STARTING VOLTAGE CALCULATION

CALCULATION NO 4

SUBSTATION SPACING ANALYSIS - TRAIN STARTING VOLTAGE DROP CALCULATION DURING TRACTION POWER SUBSTATION OUTAGE CONDITION

The Traction Power Substation spacing are based upon the train voltage conditions under normal and abnormal system operating conditions.

A. System Impedance Parameters

1. Transformer Impedance

Consider 20 MVA Transformer with 8% impedance on its own base.

$\mathrm{MVA} := 20 \qquad \mathrm{KV} := 25$

$$Z_{tr} := \frac{\mathrm{KV}^2}{\mathrm{MVA}} \cdot 0.08$$

$$Z_{tr} = 2.5$$

Based upon X/R ratio of 25 the impedance value will be as follows:

Ztr = (0.1 + j 2.5) ohms

2. Contact Wire - 4/0 Hard drawn Copper: Impedance (Zc)

Consider 30% worn wire

Zc = (0.303 + j 0.497) x (1/ 0.7) ohms/ mile

Zc = (0.433 + j 0.71) ohms/mile at 50 degree C

3. Messenger Wire - 350 kcmil copper : Impedance

Zm = (0.1845 + j 0.466) ohms/mile at 50 degree C

4. Ground Wire 4/0 ACSR : Impedance

Zg = (0.592 + j 0.581) ohms/mile at 50 degree C

5. Running Rail (130 lbs/yard) : Impedance

Zr = (0.30 + j 0.415) ohms/ mile

6. Impedance of parallel combination of contact wire and messenger wires (Zp)

$Zp = (Zc \times Zm) / (Zc + Zm)$ ohms/mile at 50 degree C

$Zp = [(0.43 + j\,0.71) (0.18 + j\,0.47)] / [(0.43 + j\,0.71) + (0.18 + j\,0.47)]$

$Zp = (0.14 + j\,0.28)$ ohms/mile $\qquad |Zp| = 0.31$ ohms/mile

7. Impedance of the return circuit (Zn) ,Parallel combination of the four rails without the effect of ground wire to be part of negative return current

$Zn = Zr/4$

$Zn = 0.25 (0.05 + j\,0.415)$

$Zn = (0.02 + j\,0.11)$ ohms/mile $\qquad |Zn| = 0.11$ ohms/mile

B Train starting voltage drop calculations

Maximum trains expected at one time on both tracks between two adjacent substations in the zone of a outage substation will be around six. For the voltage drop calculation analysis, lets consider that the trains are configured as shown in the attached sketch SK-1.

Consider two trains starting simultaneously at the outage substation each with starting current of (Is) and other trains are running drawing approximately half the starting current as shown. Question is, what is the value of distance (D) so that the train starting voltage is within acceptable limits.

$Zp \times Is \times 0.5\,D + Zp \times 0.5\,Is \times 0.5\,D + V + Zn \times Is \times 1.5\,D + 4 \times Is \times Ztr = 25$

$(0.75 \times Zp + 1.5 \times Zn) \times Is \times D + 4 \times Ztr \times Is = 25$

$K1 \times Is \times D + K2 \times Is = 25 - V \qquad VD = 25 - V$

$D = (25 - K2 \times Is) / K1 \times Is$

$D = 1/K1 \times [(25/Is) - K2]$

Please note that the current may be considered at a power factor of 0.85 lagging.

The absolute values of the constants K1, contant K2, and current (Is) will be used. Please note that the starting current value in the above equation will be in kiloamps. Thus considering the starting current including the HEP power around 400 amps.

$|\mathrm{Is}| = 0.4$

$|1/K1| = |1/(0.14 + j\,0.37)| = 2.53$

$|K2| = |4 \times (0.1 + j\,2.5)| = 10$

$D = |1/K1| \times [(VD/|\mathrm{Is}|) - |K2|]$

$D = 2.53 \times [(VD/0.4) - 10]$ --(1)

The plot between distance D and the voltage drop VD of above equation (1) are indicated in the attached graph

Thus for VD = 5 kV, the value of distance D will be in the order of only 6.32 miles.

For VD = 7.5 kV , the value of distance D will be in the order of 22.14 miles

This calculation concludes that the distance between the substations may be considered upto 22 miles and two simultaneous trains will be able to start with minimum pantograph voltage of 17.5 kV.

Lets consider that the starting current of the trains are some what smaller due to limited maximum train speed beteeen the relatively closely spaced stations. Thus for Is = 375 amps the equation (1) will be as follows:

$D = 2.53 \times [(VD/0.375) - 10]$ --(2)

For VD = 5 kV from equation (2) above distance D will be in the order of 8.43 miles and for distance D equal to 20.5 miles the VD will be 6.8 kV . Thus the minimum train voltage will be 18.2 kV.

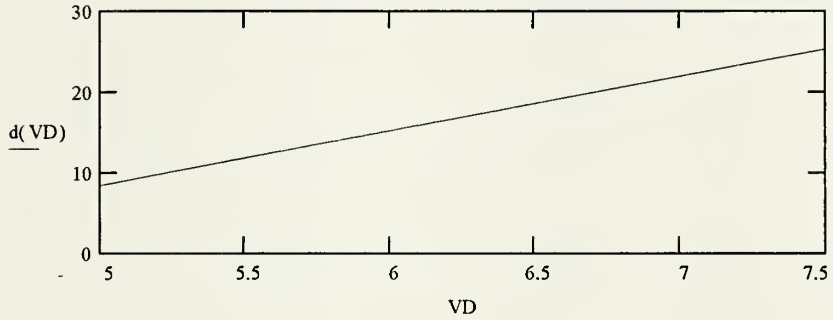
Although above calculation scenario will be very rare to have two simultaneouly trains starting at the same outage substation, however, it provides the basis that the substations spacing should not be more than 22 miles.

CALTRAIN ELECTRIFICATION PROJECT

Graph between distance (D) and voltage drop (VD) for the equation indicated below

$VD := 5, 5.5 .. 7.5$

$$d(VD) := 2.53 \cdot \left(\frac{VD}{0.375} - 10 \right)$$



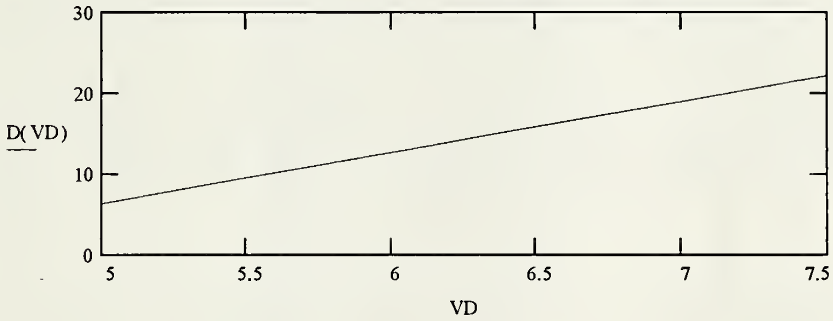
Graph #2 : Plot distance d(VD) vs voltage drop (VD)

CALTRAIN ELECTRIFICATION PROJECT

Graph between distance (D) and voltage drop (VD) for the equation indicated below

$VD := 5, 5.5 .. 7.5$

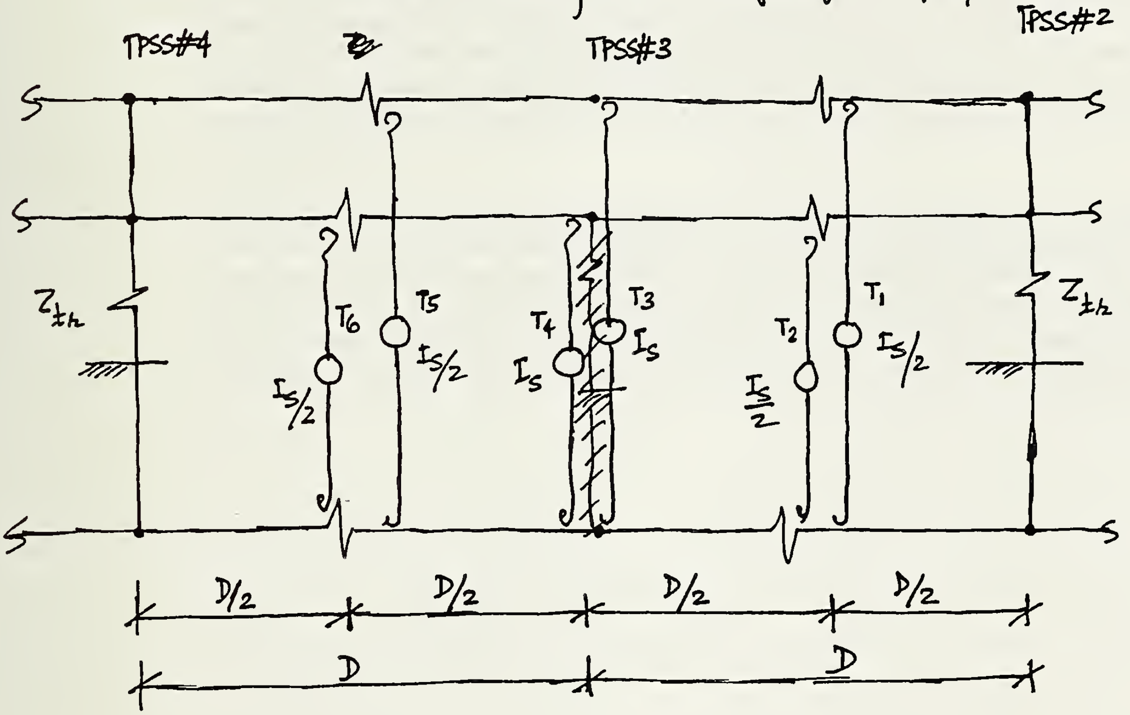
$D(VD) := 2.53 \cdot \left(\frac{VD}{0.4} - 10 \right)$



Graph #1 : Plot distace D(VD) vs voltage drop (VD)

TPSS # 3: OUT OF SERVICE

Z_p = OCS contact wire specific imp./mile
Z_n = Running rails specific imp./miles



TOTAL OF SIX(6) TRAINS BETWEEN TPSS#4 & TPSS #2

TRAINS T3 & T4 VOLT. DROP CALCULATION IS CHECKED.

Let VOLT. OF Trains T3 & T4 during starting should be V_T.

FIG. 1. TRAIN CONFIG. & CURRENTS DURING TPSS # 3 OUT OF SERVICE AND TRAINS STARTING NEAR TPSS #3.

CALCULATION NO 5

TRAIN STARTING VOLTAGE DROP CALCULATION FOR SF YARD TRACTION POWER SUBSTATION OUTAGE CONDITION

Consider TPSS near San Francisco yard to be out of service. Consider one train is starting at the terminal station and other three trains are ready and drawing HEP power only. Assume that there is another train near the yard location moving towards terminal station. It is expected that there are two more trains one on each track say 7.5 miles away from the substation drawing say 150 amps each as shown. Refer to attached sketch SK-2 for the configration of the trains and the impedance data for the train voltage calculations analysis. For the OCS wire and running rail impedance values refer to calculation # 4

As the trains are symmetrically located on the two tracks and the OCS switch at the terminal station is closed for this emergency condition, thus providing equal load sharing between the two OCS system' s of the two tracks configuration i.e inbound and outbound. Following parameters and equation apply to derive the voltage of the starting train at the terminal station. It is assumed that the TPSS also supplies approximately 500 amps instantaneous load for the trains on the south side tracks of the substation.

$I_1 := 0.35 \qquad I_2 := 0.30 \qquad I_3 := 0.4$

$I := I_1 + I_2 + I_3 \qquad I = 1.05$

$D_3 := 7.5 \qquad D_2 := 7.5 \qquad D_1 := 1.8$

$Z_{tr} := 2.5 \qquad Z_p := 0.31 \qquad Z_n := 0.11$

$$Z_{np} := \frac{Z_p}{2} + Z_n$$

$Z_{np} = 0.265$

$$VD := \left[D_3 \cdot (I_1 + I_2 + I_3) + D_2 \cdot (I_1 + I_2) + D_1 \cdot I_1\right] \cdot Z_{np} + Z_{tr} \cdot (I + 0.5)$$

$VD = 7.421$

$V_{train} := 25 - VD \qquad V_{train} = 17.579$

Please note that this voltage is very near to the minimum desirable voltage of say 17.5 kV for emergency conditions. The train voltage will be improved if the starting current of the train is lowered by considering low speed or the tractive power to the other trains on the system is shortly interrupted to start the farthest train as considered in this example.

This calculation suppots that the second TPSS from the San Francisco Yard TPSS should not be more than 15 to 16 miles away.

ICF KAISER ENGINEERS

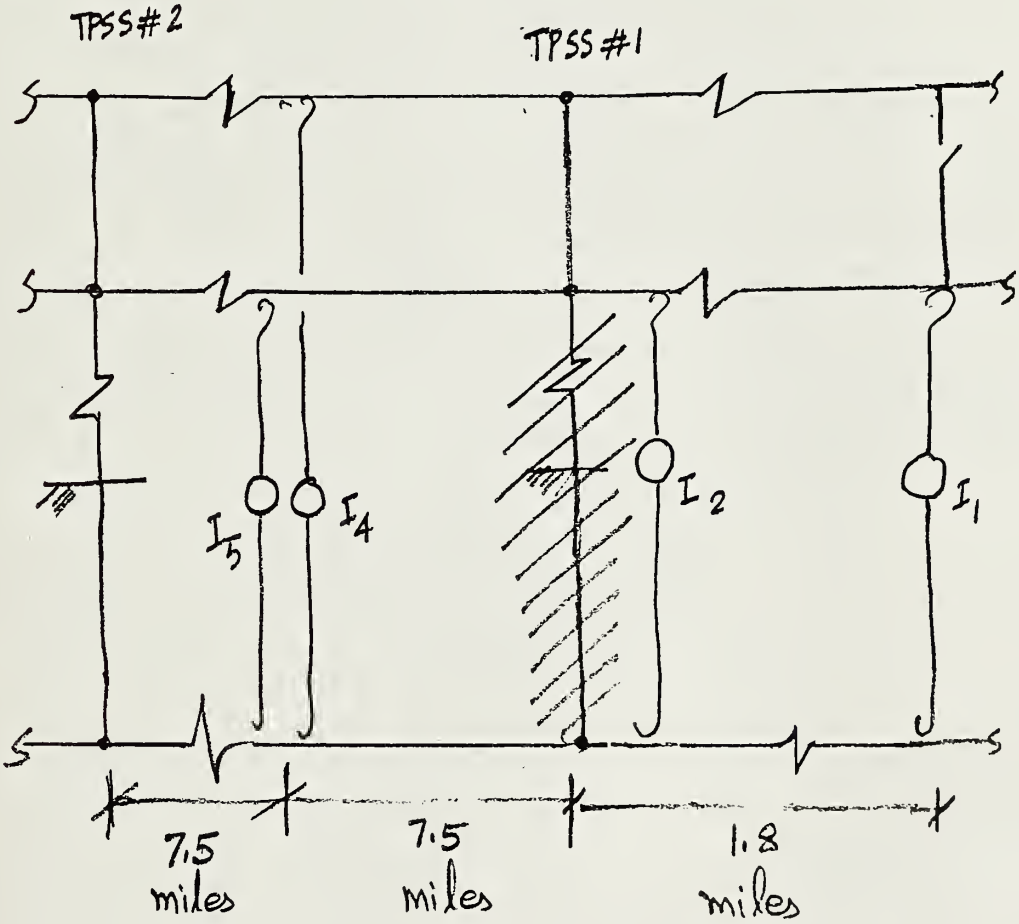
Job No. 65928-004

Sheet 1 of 1

25KV AC ELECT. SYSTEM ANALYSIS

DESIGNED BY D. PAUL DATE

CHECKED BY DATE



$I_4 = I_5 = 200\,A$

$I_4 + I_5 = I_3 = 400\,A$

$I_2 = 300\,A$

$I_1 = 350\,A$

FIG. 2. TRAIN CONFIGURATION FOR VOLT. DROP CAL

APPENDIX C

CALTRAIN SAN FRANCISCO DOWNTOWN EXTENSION PROJECT DUAL MODE POWER PACK ANALYSIS AND ELECTRIFICATION OPTIONS RECOMMENDATIONS

PREPARED FOR

PENINSULA CORRIDOR JOINT POWERS BOARD

Prepared by

ICF KAISER ENGINEERS, INC
OAKLAND, CAL

Issued
January, 1997

TRAIN PROPULSION ALTERNATIVES FOR THE PROPOSED CALTRAIN EXTENSION TO THE TRANSBAY TERMINAL

Introduction

Extension of Caltrain service to the San Francisco Transbay Terminal will require operation in 6,700 feet of tunnel. For several compelling safety reasons, it has been determined that diesel operation will not be allowed. Alternative fueled locomotives, e.g., liquefied natural gas or compressed natural gas, have been deemed unacceptable because of similar concerns. Only electric operations appear feasible.

Ultimate electrification of the JPB rail service south of San Francisco to San Jose is planned, albeit on a long timetable. Catenary-supplied power of 25,000 volts AC has been selected as commercially and operationally the most desirable. Therefore, any initial or intermediate steps involving partial electric operation should be at that same voltage, in order to minimize lost costs.

Concepts Considered for Extension to the Transbay Terminal

Three concepts, representing the potentially most possible options from an engineering and operating point of view, were considered.

- Adding an electric locomotive to each inbound train, and taking it off each outbound train, at a location between the proposed 16th Street storage yard and the portal.
- Replacing the present F-40 diesel fleet with new dual mode (diesel and 25,000 kv AC electric) locomotives.
- Retrofitting the existing F-40's to work with a power pak, a separate car body carrying the necessary equipment to allow the F-40 to propel and control the train with power from a catenary while the prime mover diesel engine is shut down. In essence, the concept makes the F-40 a dual mode locomotive by semi-permanently coupling the power pak to it.

The first two concepts were discarded fairly early in this study process.

- Adding and taking off the electric locomotives would add serious delay (five to ten minutes) to train operation because of the need to change the source of air and head end power. This delay would have the effect of making the service less desirable from the customers' point of view. This process (adding and cutting electric locomotives) would also add significantly to operating cost; since additional crews to operate the electric locomotives would be required.
- Replacing the existing fleet of F-40 locomotive with dual mode locomotives would be expensive ($80 to $90 million in 1996 dollars). There are no diesel / 25,000 volt AC dual mode locomotives currently available in the U.S. market and the prices quoted would be subject to the commercial viability of the redesigned dual mode locomotive.

Parenthetically, it is noted that retrofitting the existing F-40's to function as dual mode locomotives was examined by Morrison-Knudsen in 1987 in their earlier analysis of the extension of commuter service in San Francisco. Their analysis indicated that it may be physically possible to reconfigure the F-40 for dual mode (diesel / 750 volts) service. Their conclusion was that the necessary modifications and additions in the confines of the car body size of the F-40 would result in an unmaintainable unit because so much equipment would be in such a small space. Their analysis included the observation that the FL-9, the 1950's dual mode (diesel / 750 volts) locomotive required a car body four feet longer than the F-9 diesel locomotive that was the basis of the FL-9. Their conclusion was that the conversion was infeasible. Briefly revisiting their analysis, to see if advancing technology has produced any different conditions has confirmed their earlier conclusions.

Study Conclusions

The following conclusions were reached as a result of this study effort. The details of the study effort are described herein.

1. Operation of trains powered with diesel locomotives from Gilroy to the north end of Tunnel No. 1, and changing to electric operation there, is possible.

2. Use of the power pak concept is completely viable. Unit costs for the acquisition/construction of the power pak units can be held under $2 million each, subject to the procurement considerations shown below.

3. Use of a lower voltage in the tunnel than the 25,000 kv AC planned for overall electrification should be evaluated.

Evaluation of the Power Pak Concept

The power pak concept of using ~~an~~ equipment in an additional rail car to provide dual mode capability to the existing F-40's was explored in some depth. The power pak would carry the pantograph for electric collection from catenary (and/or third rail shoes), the transformers, rectifiers, compressors, etc. necessary for electric operation and to provide the F-40 with traction and ancillary power when the F-40 prime mover was shut down. This car would be semi-permanently coupled to the locomotive, so that it would be between the locomotive and the train. The sheet shown in Figure 1(or those concepts) was developed and provided to interested parties for comment and estimates.

[illegible] + [illegible]

Those interested parties have so far included LTK Engineering Services, General Motors, General Electric, New Jersey Transit, American Electric Power Service Corporation, and Jerry Pinkepank. The following questions were asked of each party.

1. Are there any fatal flaws in the concept?
2. If the power pak were operational, what would be the problems, and how would they affect service reliability and cost?
3. Is there a better answer?
4. What would have to be done to the F-40?

In the briefest possible form, the answers were ***1. No, 2. Minor, 3. Probably,*** and ***4. Not much***. Specific summary discussion of responses follows. More complete responses are shown in the appendix.

1. **Are there any fatal flaws in the concept?**
   No respondent saw any fatal flaws in the concept. All pointed out that significant equipment and weight would be avoided if direct current were used, either from third rail or catenary or both in combination. Several respondents added comments about the potential for savings in tunnel construction if the propulsion current delivery in the tunnel was from third rail. They commented that the concept of using both third rail and catenary for current delivery is time tested and relatively trouble-free. Similarly, the concept of a locomotive that can operate on both direct and alternating current appears to be historically tested.

2. **If the "Power Pak" were operational, what would be the problems, and how would they affect service reliability and cost?**
   All respondents identified the addition of a nonstandard component to the system as a problem. The need for power conditioning on the power pak to avoid damage to traction motors was mentioned. None of the respondents seemed to see any singular problems.

3. **Is there a better answer?**
   Each respondent was concerned with the nonstandard aspects of the Power Pak. Most thought that a dual mode locomotive was a "better" answer. The commercial suppliers of new locomotives, and LTK, thought that the cost of assembling the power car would approach the cost of a new dual mode locomotive. Others were less pessimistic.

4. **What would have to be done to the F-40?**
   Not every respondent directly answered the question, but none thought the modifications would be extensive. EMD estimated $90,000 to $100,000 in material, and LTK estimated $250,000 to $300,000 each for the twenty F-40's JPB operates. De Leuw, Cather judged the EMD and LTK estimates to be approximately equal.

Figure 1

Caltrain Extension - Electrification Locomotive Concepts

1. When the extension of Caltrain to a new, downtown terminal station location is completed, trains will operate more than one mile in the tunnel. The station platforms will be below grade.

   - Electric operation is required. No diesel operation in the tunnel is allowed. Alternative fuel concepts are not acceptable.

   - Budget constraints (at least) make initiating electric operation on the entire line at the same time impossible.

   - Electric operation at 25,000 volts, AC, is required. Third rail is not acceptable.

2. Obviously, what is needed is a dual mode (diesel-electric and 25 kv AC) locomotive. Such a single unit does not exist. Analytic findings to date include:

   - Retrofitting the F-40's is not possible due to space within the car body.

   - Purchase of a fleet of new, dual mode, locomotives, or a fleet of electric locomotives to mu with the F-40's is deemed not possible because of budget constraints.

   - The apparent "best" solution is a "slug" locomotive unit, "power pack" to carry a pantograph and transform current from the overhead to be used by the F-40.

3. The F-40 would remain the controlling locomotive, and the pair, the F-40 and the power pack, would remain coupled in all normal service. When operating from the 25 kv catenary, the diesel prime mover would be shut down. The transition between the two sources should be transparent to the customers, and occur while moving. Conceptually, it is envisioned that

   - The F-40 head end power (HEP) and air compressors would be electrically powered from either the F-40 prime mover, or the power pack, as appropriate.

   - The F-40 could operate without the power pack coupled.

   - The traction motors of the power pack and the traction motors of the F-40 would both operate in the electric mode. (Early analysis indicated that the maximum train size with one F-40 on the design grade, 3%, was six or seven cars. The design train size is 10 cars.)

   - The power pak would have no controls or independent operating capability.

   - The required additional control functions (e.g., pantograph control, shutting the diesel down inbound and starting it outbound, with appropriate alarm lights) would be train lined for control from the cab car as well as the F-40 cab.

   - Modifications to the F-40 to accommodate this revised operation would be carried out during a planned F-40 overhaul.

Other Issues Concerning the Power Pak Concept

Operating Costs

The power pak concept will require transporting the power pak over the railroad during all operations, since all trains will go to and from the new terminal. The power pak will weigh 60 to 90 tons, depending on the final configuration. This will consume additional fuel, similar to adding one car to each train. Similarly, this additional unit will add some potential small increment to track maintenance. In the same vein, adding an additional 20 pieces of rolling stock will add to equipment maintenance costs. In general, it would be assumed that the cost would be less than for a locomotive or car.

None of these costs are substantial, but all are real and recurring. For example, about $150,000 in additional fuel cost will be spent hauling the power pak in trains.

Track Use at Transbay Terminal

The power pak concept will add 65 to 89 feet to the length of each train, depending on the car body used. Since the power pak would be coupled to the locomotive, it would not increase the length of the platform needed. It would however, increase the length of the track needed between the end of the platform and the clear point for the track at the interlocking signal. This potentially adds to the construction cost of the terminal.

This may be a significant cost, but would be a one-time capital cost. Any additional track needed would probably be of such a small quantity as to not be noticed in construction or maintenance costing.

Requirements for Additional Power on Trains

For the design base train of 10 cars, one F-40 appears to be marginally adequate power for the grades and curves of the proposed route to the Transbay Terminal. Addition of the power pak to the design base 10 car train may require that the trucks of the power pak be powered, or addition of an additional F-40 (with or without an additional power pak). Powering the trucks adds to the cost of the power pak, and adding an additional F-40 to the train increases the potential complexity of the F-40 modifications if one power pak is to supply two F-40's. Addition of an F-40 with or without a power pak adds to the length of clear station platform track required, but does not increase the length of platform needed.

Provision of this additional track may be a significant cost, but would be a one-time capital cost. The possibility exists that an additional locomotive would be necessary on longer trains at least one and possibly two cars sooner because of the addition of the power pak.

Transmission of High Voltages Between Locomotives and Power Paks

GE identified potential safety problems associated with the high voltage, high amperage currents passing between the power pak and the locomotives. Certainly, these connections would require special care and instructions. The concept of cabling high voltage, high

amperage power is not new, and can surely be resolved.

Fire/life Safety Considerations with Dual Powered Locomotives

NJT commented on the requirements Metro-North encountered with respect to fire/life safety considerations because the locomotive has a tank full of fuel that can present a safety hazard in the event of derailment and tank rupture. Metro-North has apparently provided special tanks on its locomotives to avoid the possibility of spillage. In view of the concerns following the recent tragic MARC - Amtrak collision, this matter may receive more focused review.

Use of the Power Pak as a Cab Car

One suggestion offered was to consider the power pak as the cab car, to address the cab/car concerns expressed after the recent tragic MARC - Amtrak collision. This option appears to require platform length extension, and will increase the power pak cost, to provide control cab capability. The concept was not developed further.

what about ?? Europe/Asia/Australia?

Use of a Modified Electric Locomotive for the Power Pak

Use of a modified used electric locomotive could be the lowest cost solution, to the extent they are available. Unfortunately, the used electric locomotive market is very small. The locomotive most available is the E-60. NJT has six, out of service, E-60's that would be currently available. The E-60 has been unacceptable in some services, but for 79 miles per hour maximums, it is probably suitable. Modifications would have to be made to allow for multiple unit operation with the F-40 so that all functions were available with either the F-40 or the E-60 not providing power.

Procurement Considerations

If the decision is made to pursue the power pak concept, the procurement process may be somewhat more difficult than average. The traditional locomotive supply professionals, manufacturers and consultants, believe that the power pak does not have wide commercial application. They believe that any case that involved use of a power pak on a long term basis, a dual mode locomotive would probably be a better answer. If the long-discussed freight electrification in southern California were implemented, then possibly power paks would have wider commercial application. For these reasons, an RFP for development would probably not generate wide response.

In order to achieve the "best" life cycle costs, probably using the power pak concept, a tunnel propulsion development program managed by JPB is probably appropriate. This program would:

A. Evaluate alternatives and balance the costs for tunnel design (clearances and station track length) and propulsion alternatives.

B. Identify sources of components and revised concepts for the Power Pak program

    I. Act on short term opportunities in time windows that may appear, (this is

analogous to Dallas Area Rapid Transit's identification of the availability of VIA rail diesel cars for retrofit, and completing a conditional purchase order to ensure the option would be available)

ii. Evaluate emerging electric propulsion technologies (e.g., microprocessor controls, AC traction motors, distributed power, fuel cells, electric braking, etc.) to determine applicability and relevance to the program,

iii. Reevaluate, on a continuing basis, JPB decisions relative to propulsion sources, schedules, funding sources and restrictions and public-private partnership opportunities.

Files, 4.12

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February 29, 1996
File No. 2523

Mr. Charles C. DeWeese
Principal Railroad Project Manager
DeLew, Cather & Company
3075 East Flamingo Road, Suite 102A
Las Vegas, Nevada 89121

Subject: Caltrain Extension
Electrification Motive Power Concepts

Dear Mr. DeWeese:

In reference to your February 12 letter, we have reviewed the power car ("power pack") concept for use on Caltrain operations for the interim period before complete electrification of the system. Such an arrangement would enable the JPB to obtain better utilization and return on investment of the existing fleet of 20 F-40 locomotives. We have, in addition, considered some variations to the "power pack" concept as presented to us, to better explore the options available and their implications. We offer the following comments and thoughts for your further consideration:

A. BASIC CONCEPTS AND CRITERIA

The Caltrain program could involve an investigation of the full range of dual power locomotive options ranging from single unit to dual unit configurations, the utilization of power cars, and the possible incorporation of some apparatus into a passenger-carrying car. However, per your request, we have addressed only the power car option (with several variations) and some thoughts on new locomotives.

Existing Caltrain F-40 Units Operating in Conjunction with Electric Power Cars: This concept would utilize a specially modified F-40 locomotive coupled to another vehicle carrying the electric power mode apparatus, operating under common control. This configuration, an electric "B" unit, has the possibility of utilizing either new or existing carbodies and some other components for the power car. For non-electric operation, the primary power source would be the conventional F-40 diesel engine. The electric power car could be designed to operate from either an AC or a DC electrification system. It would require power conditioning equipment for the basic on-board power source in the electric mode. Weight and cost savings would be realized with a DC power supply, as will be discussed later. Our rough calculations indicate that an F-40 and a 90-ton power car with a fully loaded ten-car train could just start the train on the 3% design grade and perhaps reach a balance speed of ten mph. It would be prudent, therefore, to provide the power car with traction motors to assure routine adequate performance for this critical condition.

Major criteria are:

- All operator controls available in F-40s and cab cars.
- Mode change from diesel-to-electric, or from electric-to-diesel possible while moving or stopped.

A concern is that the F-40 diesel engine will require a certain amount of time for starting, warm-up and stabilization of fluid and pressure levels before it is able to provide propulsion power during the electric-to-diesel transition. Thus, the diesel propulsion mode will not be immediately available upon exiting the tunnel and the train will be required to continue its operation in the electric mode until the diesel mode is available. Therefore, extension of the electrification considerably beyond the tunnel portal will be necessary to provide HEP and propulsion power during transition. The actual length of additional electrification required will be a function of the maximum allowable speed and the mode changeover time. It is assumed to be from two to five miles, and should be installed on all tracks in order to avoid operational limitations when reverse running is in effect.

B. MOTIVE POWER SOURCE AND CONDITIONING CONSIDERATIONS

A primary objective of the motive power design should be to minimize the total number of components required by sharing equipment used in the electric and diesel modes of operation. Certain components, such as the diesel engine itself and the electric power conditioning apparatus, clearly can function in only one mode, while traction motors and some locomotive auxiliary components, such as the battery charger, could function in both modes. The point in the locomotive propulsion power circuitry at which common components may utilize either source of power is significant in the reduction of redundancy and the associated weight and cost.

The F-40 diesel-electric locomotives use variable voltage three-phase alternators and rectifiers to produce a DC output. This DC output is fed directly to series-type DC traction motors.

Propulsion power conditioning systems used on many electric locomotives employ phase control rectifiers on single phase power with smoothing reactors to feed DC traction motors. Recent offshore single-phase electric locomotives use a transformer-converter-inverter circuit with brushless AC traction motors.

The Caltrain F-40s now provide HEP by means of a main engine-driven alternator with the locomotive in "RUN" and its engine operating at a constant 900 RPM. With the locomotive in "STANDBY", HEP is provided from the main traction alternator with the engine at lower speed. Such an arrangement precludes the use of either of these HEP sources in the electric mode. The same is true of the air compressor, which is also directly driven by the main engine. Thus, the power car must have an

HEP supply and main reservoir air source in addition to a traction power collection and conversion function and traction motors. Dynamic braking might also be included if the 3% design grade is a significant influence. The power car, therefore, almost becomes an electric locomotive without operator controls.

C. CONTROL REQUIREMENTS

Efficient operation of the Caltrain locomotive imposes two fundamental control requirements:

1) The changeover between electric and diesel modes, including starting and stopping of the diesel engine and the raising and lowering of the pantograph, must be performed with the train in motion.

2) The changeover must be controlled remotely from either the locomotive cab or a cab car.

   In addition, indicators must be provided in cabs of both cab cars and locomotives to annunciate normal and fault conditions to the operator.

These conditions necessitate an automatic sequence of operation with a minimum of trainline functions.

Two basic control functions are required for normal train operation:

- Mode Selection - a two-position selector switch for electric or diesel mode.
- Engine Control - a two-position selector switch for engine start/run and engine stop.

In addition, two emergency control functions are required:

- Emergency Pantograph Lowering - a switch at each control station.
- Emergency Engine Stop - a throttle position on locomotives and a separate switch on cab cars.

The two normal control functions and the two emergency functions will require trainlines which may not be available in the existing 27-wire locomotive trainline control circuits.

From an operational standpoint, the control functions listed above would operate in the following manner:

Electric-to-Diesel - (outbound from San Francisco). With the train operating in electric mode, and HEP energized, the operator moves the Engine Control Selector to "Start/Run", initiating the following automatic sequence:

- start turbocharger auxiliary lube oil pump
- "creep" engine through one revolution
- start fuel pump
- crank until engine starts
  (Note also that if a diesel engine has been "dead" for more than 48 hours, a lubrication priming cycle should be carried out. Thus, if for some reason a train is stored in the station the diesel traction engine could not be started immediately.)

The engine is allowed to idle to stabilize temperature and pressure. The operator then moves the throttle to "Idle" and the Mode Selector to "Diesel" and the following automatic sequence of transfer takes place:

- transfer HEP power
- transfer propulsion power
- open primary circuit breaker
- lower pantograph

The operator may then open the throttle and assume control of the train in the "Diesel" mode.

Diesel-to-Electric - (inbound to San Francisco)
With the train operating in Diesel mode and HEP energized, the operator moves the throttle to idle and the Mode Selector to "Electric", initiating the following automatic sequence of transfer:

- raise pantograph
- sense catenary voltage
- close primary breaker
- transfer HEP power
- transfer propulsion power
- engine idles

The operator them moves the Engine Control Selector to "Stop", resulting in the following automatic sequence:

- energize engine shut down solenoid
- start turbocharger auxiliary lube oil pump
- stop turbocharger auxiliary lube oil pump after cool down (timed)

The operator may then assume control of the train in the electric mode with the traction motors of both the power car and the F-40 functioning.

D. F-40 MODIFICATIONS

Certain modifications to the F-40s would be necessary for them to operate in dual mode service. These are listed below:

- Add MU control functions for dual mode operation.
- Add layover heaters for oil and cooling systems (to operate from HEP).
- Modify HEP circuits to accept power from either F-40 or electric power car.
- Add battery charging system for use in electric mode.
- Add remote diesel engine start, automatic sequence logic, and interlocks.
- Add power and control cabling (possibly at both ends), switch gear and control apparatus to control and supply power for traction motors and blowers from electric power car.
- Add control for electric power car dynamic brake, if appropriate.

E. ELECTRIC POWER CAR REQUIREMENTS

To reduce the initial cost of the power car, it is suggested that 20 used diesel locomotives of the same type be purchased and converted. The locomotives should be stripped to the frame. The cab and short hood should be removed and replaced with a modified hood extension incorporating as much existing structure as possible. The frame/body should then be fit out with power conditioning and control equipment, dynamic brake apparatus if appropriate, an air compressor, an HEP source and a pantograph. The weight of the power car would be about 90 tons.

If the electrification system is at 25 kV, the power car would require a main transformer. If the power supply is at 1500 VDC, the catenary voltage could feed the power conditioning directly. Basic chopper or thyristor phase-control rectifier power conditioning circuits should be used to power the traction motors of the power car and the F-40 diesel locomotive. Certain control functions would be necessary to accommodate the characteristics of the F-40 traction motors (wheel slip, acceleration control, etc.).

The power car's HEP converter, whether an MA set or static inverter, should be configured to accept input power from a DC bus energized from the main power conditioning apparatus of the electric power car. The HEP converter would be sized to accommodate the specified loads as well as to drive the diesel locomotive's traction motor blowers, battery charger and other auxiliary loads.

As previously noted, because the F-40 air compressor is driven by the main diesel engine, the electric power car must be provided with a motor-driven compressor to supply main reservoir air when in the electric mode.

It would be necessary to add traction motor and auxiliary power cables and switch gear to permit mode change.

F. NEW DUAL POWER LOCOMOTIVES

For more than thirty years the only dual power locomotives in North America were the EMD Model FL9 originally built for the New Haven. However, last year, General Electric and Amtrak introduced 10 P32 AC (Genesis) dual-mode units. Metro-North then ordered five more of these units to replace some of its FL9s. EMD has an order from the Long Island Rail Road for 10 new units with similar performance to be delivered in the relatively near future.

The P32 AC and the EMD unit have relatively conventional diesel engines and main alternators, but utilize inverter technology for AC traction and HEP. Their electric operation uses the same traction and HEP inverters powered from a conventional 750 VDC third rail. Recognizing that Caltrain has rejected a third rail design, we believe that the P32 AC or the EMD unit could easily be fit with a pantograph for power collection from an overhead source at 1500 VDC. As will be noted, the catenary could be designed for later conversion to 25 kV AC.

The P32 and the EMD equivalent are attractive for several reasons. They are modern state-of-the-art locomotives designed for precisely the operating conditions that Caltrain is facing. They are (or soon will be) proven designs of the two major U.S. locomotive builders. They can meet all of Caltrain's requirements in a single unit, thereby minimizing maintenance as well as station and yard track requirements. There will be a market for their resale when the electrification program is complete, and although the Caltrain F-40s would become surplus if P32 ACs were purchased, the F-40s are now in some demand by other operators. The power cars, on the other hand, while extending the usefulness of the Caltrain F-40s, would have little if any market beyond the Caltrain operation. The economics and timing of this issue require thorough investigation.

G. POWER SOURCE

25 Kv AC

The selection of 25 kV AC as the ultimate operating voltage is suitable for system-wide application over a long distance, however, difficulty could be encountered within the tunnel and station area. The strike clearance required for electric catenaries in a tunnel is dependent upon many factors, including voltage, pollution and humidity as

well as the design of the catenary itself (e.g., permitted sag, permitted uplift, distances between supports, etc.).

Although no problems are anticipated with the 25 kV catenary voltage, the selection of a lower voltage could result in some savings in the construction cost of the tunnel and station. All things being equal, a lower voltage would imply a smaller tunnel bore. It is not unusual for a system to be designed to operate in open territory at 25 kV and within tunnels at 11 - 12.5 kV because of a combination of the factors mentioned above. The locomotive transformers could be designed with dual windings and the controls required for automatic voltage sensing to switch from one range to the other.

Please note that in our research it was found that DeLeuw Cather Co. produced a report in 1979 titled "Analysis of Overhead Clearances in Electrified and Non-Electrified Territory Between Washington and Boston, Task 204." We do not have a copy; however, reference to this document may assist you with your further work in this area.

DC Power

Although the Caltrain route may ultimately be electrified at 25 kV 60 Hz, it is believed that this work will not be completed quickly. Even though a 25 kV power car is completely feasible, we believe that certain economies can be effected in the design of the power car if the initial tunnel electrification were to be installed at 1500 VDC. The catenary could be designed and installed with all the necessary clearances, insulation and other physical protection required for the alternate 25 kV system, but initially energized at a lower DC level.

Such a plan would reduce the cost and complexity of the power car by eliminating the need for the heavy main transformer. A main bus of the power car would be directly energized at 1500 VDC from the pantograph and then supply a chopper for DC traction loads and an HEP inverter for AC loads.

The "down" side of this plan would be the acquisition of wayside DC power supply equipment (we believe two substations will be needed) which would become superfluous when the 25 kV AC system becomes operational.

H. POWER COLLECTION (DC)

Inherent in the review of DC power car/dual power locomotive options is the choice of power collection method. Two approaches are viable: power collection via pantograph from an overhead catenary, and power collection via third rail.

Overhead Catenary

The use of DC electrification with an overhead catenary is a feasible option with few technical risks. Voltage could be at 750 VDC, 1500 VDC or even 3000 VDC, with the higher voltages offering better transmission capabilities and requiring fewer substations. As noted, the catenary could be designed as a hybrid, with wire sized for DC transmission, and insulators and physical clearances designed for 25 kV.

Such a hybrid arrangement would, however, present an issue for future planning. Locomotive traction equipment and wayside substation apparatus are very different between DC and AC systems. AC and DC cannot "share" the overhead line at the same time. Thus, when 25 kV operation is introduced, an abrupt, "D-Day"-type cutover would be necessary to drop the DC system. This transition would result in the overnight obsolescence of all motive power and wayside equipment associated with the DC electrification.

Considering such a future transition, an approach utilizing a hybrid DC/AC locomotive could also be considered. Such a unit would operate in DC mode on the DC electrification in the tunnel and terminal area and in AC mode in 25 kV territory. This arrangement is possible but would require adoption of a European design and create additional cost and complexity for the locomotive.

Third Rail

Although we understand that Caltrain has rejected the third rail concept, such a system has some advantages and could be used to distribute 750 VDC traction power. An arrangement similar to the New York-area electrification, where the new generation of dual-mode units operates, is possible. The existing GE Genesis or forthcoming EMD-built LIRR units could operate on such a system with minimal (if any) modification.

The primary advantage of third rail in this case is its compatibility with the future 25 kV AC overhead electrification system. The power collection systems are compatible with one another (as evidenced by joint DC third rail/12 kV overhead electrifications in New York Penn Station). Dual mode units (diesel/DC) and straight electric AC units could operate on the same trackage with no difficulty. In planning for the future, the DC third rail approach would allow gradual implementation of 25 kV electrified service as time and finances permit. There would be no need for an abrupt transition, with associated bunching of equipment procurement costs and operating disruptions.

The disadvantages of the DC third rail approach lie in the lower traction voltage, which would require additional substation capacity as compared with 1500 VDC or 3000 VDC systems, and the eventual obsolescence of the third rail as the AC electrification phase-in is completed.

I. MAINTENANCE, RELIABILITY AND OTHER ISSUES

The electric power car would be regarded as a locomotive for FRA requirements and thus be subject to the 92-day inspection requirement. Its overall maintenance requirements would be similar to a locomotive, less cab equipment, but with added control complexity.

As to reliability, we do not believe that the power car arrangement would have a dramatic impact. The service reliability of the power car itself can be expected to be a little better than that of a comparable locomotive due to its lower rate of usage and the physical reduction in the number of components. Any power car failures, however, would be in addition to those presently experienced with the F-40. Therefore, it is only reasonable to assume a lower level of reliability for the combined units. A separate study to quantify the extent of this point would be necessary. Operating cost estimates are similarly beyond the scope of the present study. However, it can be assumed that fuel costs for a new dual-mode unit will be less than for an
F-40/electric power car combination due to the reduction in total train weight and greater efficiency of the new locomotive.

A relatively minor point worth noting is that the signage at existing stations will have to be repositioned to accommodate the new train lengths. This would ensure continued compliance with the ADA and other requirements for the alignment of car doors relative to the platform tactile strips.

J. COST ESTIMATE

The following tabulation provides our best estimates of order-of-magnitude ranges of costs for the various requirements, alternatives and options discussed. Given the time available to prepare them, these ranges can be regarded as no better than +/- 10%.

Unit Cost Estimates

Power Car	25 kV AC	1500 VDC
New Unit	$3.95 M - $4.35 M	$3.40 M - $3.70 M
Used Locomotive	$3.50 M - $4.00 M	$3.00 M - $3.20 M

F-40 Modifications	$0.25 M - $0.30 M
Cab Car Modifications	$0.050 M - $0.075 M
New Dual Mode Locomotives	$4.0 M - $4.50 M
Substation Equipment	$0.80 M - $1.20 M

Summary Cost Estimate - 20 Units

	25 kV A	1500 VDC	New DPL
Power Cars	$70 M - 87 M	$60 M - 74 M	--------------
F-40 Modifications	$5.0 M - 6.0 M	$5.0 M - 6.0 M	($20.0 M)*
Cab Car Modifications	$1.0 M - 1.5 M	$1.0 M - 1.5 M	$1.0 M - 1.5 M
New DPL	------------------	------------------	$80 M - 90 M
Substations (2)	$1.6 M - 2.4 M	$1.6 M - 2.4 M	$1.6 M - 2.4 M
Total	$77.6 M - 96.9 M	$67.6 M - 83.9 M	$62.6 M - 73.9 M

* Estimated market value of 20 Caltrain F-40s.

From the above, it is our opinion that the "power pack" decision requires careful reassessment. Also note that the capital outlay might be reduced if new dual mode locomotives could be leased. There is less likelihood for leasing power cars because they will not have resale value. There is also a good outlook for the sale of the existing fleet of F-40s. Further, without power cars, the operating and maintenance costs would be reduced considerably from the operating scenario being considered. New dual-mode locomotives could be expected to require less costly maintenance than the existing F-40s because of their brushless traction motors.

Another factor to be taken into account is that the construction costs for the new station would be considerably reduced if the new dual mode locomotives were selected. The elimination of the power car's length (say 60 ft) from the train consist, across the width of the proposed underground station would save a great deal of construction.

The use of power cars would obviously increase the system's operating and the maintenance costs. These costs have not been estimated due to the numerous variables and would require extensive evaluation to develop. However, it is believed that the addition of power cars would increase the operating and maintenance costs in an amount roughly equal to the costs for an equal number of locomotives. If power

car maintenance requirements are, in fact, less than a locomotive's, any difference would likely be offset by the costs associated with increased train weight.

K. SUMMARY

This report may be summarized by the following direct response to the five questions posed in your February 12 letter.

1) Are there any fatal flaws in the power pack concept?

Technically, no. The proposed operations should function as intended if properly designed and implemented, but it is a complex and unique arrangement.

Economically, yes. We believe that the cost of the "power pack" arrangement will exceed that of the alternatives.

2) If the power pack were operational in the JPB fleet of 20 locomotives (15 trainsets required for weekday service) what would be the problems, and how would those problems affect service reliability and operating cost?

Complexity of the power cars would tend to reduce reliability and increase out-of-service time for maintenance and troubleshooting, with a corresponding increase in cost. The added weight of the power cars (estimated 90 tons) would affect schedules and fuel costs as though there were about 1.5 more cars in each train.

3) What do you estimate the order of magnitude costs for putting 20 power packs into service?

Dependent on catenary voltage (25 kV AC or 1500 VDC), we estimate from \$68 M to \$97 M.

4) Is there a better answer (better being defined as cheaper, or possibly more reliable) than what has been conceptualized?

✓ Yes - new dual power locomotives, as now available from both EMD and GE, working from a 1500 VDC power supply.

5) How much would the modifications necessary for the F-40 to work with the power pack add to an "ordinary" overhaul?

We estimate from \$5 M to \$6 M for 20 units.

As stated, we believe that added study beyond the scope of our assignment at this time would clarify and better define the motive power issues. However, we trust that we have answered your questions adequately for the current requirements of your program. If you have further questions, please feel free to contact us.

Very truly yours,

LTK ENGINEERING SERVICES

R B Watson

for Maurice M. Rix
Senior Engineer

RBW:eg

cc: G.N. Dorshimer
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March 14, 1996

Attention: Mr. Charlie DeWise
Consultant

SUBJECT: CALTRAIN - JPB FEASIBILITY STUDY
ELECTRIC MODE POWER COLLECTION VEHICLE FOR F40PH

Dear Charlie

This has reference to our recent discussions re the JPB (Caltrain) looking into extending their service into downtown San Francisco through a dedicated tunnel that would have overhead electrification for power. The questions you were seeking answers to and our responses are outlined below:

> **"What would be the most economical way to utilize these F40PH locomotives to operate in a dual mode fashion; as Diesel electric locomotives for most of their run and as electric locomotives in the downtown tunnel?".**

The F40PH locomotives are coming due for overhaul, and the railroad would be willing to perform a modicum of modifications to make them electric-mode compatible.

It is envisioned that a separate "power pack" vehicle would be utilized to house the needed electric-mode equipment. A complete propulsion package would also be required within the power pack vehicle, as a single F40 locomotive would have insufficient power to meet the service needs. This new vehicle would have no operating cab.

We understand the operating conditions to be the following:

Tunnel length:	about 1 mile
Tunnel Grade:	3 %
Total length of electrified run:	5 miles
Consist size:	up to 10 cars
Car Weight (loaded):	70 tons
Operating Speed:	40 mph

Given the above conditions, particular configurations are suggested. The information to follow, represents our initial assessment of how to best embody the functional requirements in two vehicles and optimize the spectrum of interface requirements and boundary conditions that result.

Proposed Configuration

F40PH

We envision the F40PH to remain largely unchanged, from a functional standpoint. Conversion of most subsystems should be discouraged, in favor of supplying the functions directly from the power pack vehicle, as there are no subsystems that easily lend themselves to dual power conversion. For instance, we see it uneconomical to reconfigure the compressed air system and the HEP system for electric sourcing, as both are mechanically driven today, and would be cumbersome to convert. What would likely be the more favorable option would be to install these features as stand-alone functions in the power pack vehicle.

Air Compressor

If converting to a motor driven air compressor is essential, one must consider that the companion alternator would need to be upgraded to a larger machine. This may necessitate the engine being shifted rearward to accommodate this modification. This could make for an unwieldy overhaul effort. Alternately, one could drive the compressor from the HEP system, but that would mean that the main engine would have to be producing HEP whenever the air compressor was needed. Furthermore, a motor-driven compressor conversion would add up to 3000 lbs. to the locomotive, depending on the exact realization chosen.

HEP System

Use of an inverter HEP system on the F40PH is also not seen as practical. To power the inverter, another generator would need to be added, for a controlled source to the inverter. However this generator is driven, its weight would be expected to be the same order of magnitude as the HEP generator / gearbox package installed today. Combining the inverter with this arrangement would add from 5000-6000 lbs. of equipment weight to the locomotive and will require locomotive rebalancing and/or addition of ballast weight at the locomotive front end. Total weight implication of this modification could be up to 9000 lbs. Further truck suspension modifications would then be required.

Traction Motor Cooling

The issue of traction motor cooling is another point. The power pack vehicle would have to be the source of some method of supplying forced air to the F40PH traction motors. Recommended ways to accomplish this feature would be to motor-drive the existing traction motor blower rather than having it mechanically driven from the engine, as it is today. HEP could be used as the power source. The new motor would likely supplant the existing auxiliary generator (which is in the traction motor blower driveline), thus necessitating the addition of a solid state auxiliary generator equivalent that could be mounted in a more favorable location. The added motor would have to be a 2-speed design, and carry changeover switchgear and a step down transformer to allow for companion alternator and HEP voltage compatibility.

Other Equipment

The F40PH would require a new tier of switchgear to allow the locomotive's traction motors to be controlled remotely. Also, high current "slug plugs" and their associated cabling would need to be installed. As well, accommodations for the interface control functions to the power pack unit would have to be made. This would involve another MU-style control jumper arrangement, or multiplexing of this information onto existing trainlines.

Budget Costing

Rough Cut Budget Costing for modification of an F40PH would be solely dependent on the configuration chosen, but would be, in the minimal form, about $90,000 to $100,000 for the essential materials only. Labor and electrical cabinet work would need to be considered separately, based on prevailing rates.

Power Pack Vehicle

The contemplated power pack vehicle would have to be sized as about a 5 to 6 MW unit, including power required to supply HEP. This is based on the need to maintain a 40 mph speed in the tunnel with a 10 car train on a 3% grade (must remember to include the weight of the F40, as well as the power pack vehicle in performance simulations).

In short, we would expect that this power pack vehicle would need to have all the subsystems of a normal electric locomotive, except a cab and associated controls. It would also need to be burdened with the added logic and control for providing power to, and interpreting the status of the traction motors on the F40PH, as well as its own motors. This would lock the new vehicle into using common motors throughout; in essence, the vehicle would operate as an eight axle locomotive with D77 motors.

Pricing of this vehicle should be very similar to a new electric locomotive, as the removal of the cab would be offset by the need for a specialized design that will be required to house and control the D77 motors required for operation.

The above, Charlie, gives our "first pass" at a workable configuration. At this point, it seems as though that F40 is not the best candidate for modification into a dual mode vehicle. In whatever way we stack it up, it seems as though that the cost to provide electric-mode transportation is going to be on the order of purchasing an electric-mode locomotive.

We trust that this information is sufficient for this stage of the investigation. If you have comments or questions on any of the information presented here, please just call.

R E Wright

R. E. (Rob) Wright
Area Manager, Passenger
Locomotives
519-452-5192/F452-5384

FACSIMILE TRANSMITTAL SHEET

TO:

FRI 4/12

NAME: Mr. Charles C. DeWeese

LOCATION: De Leuw, Cather

TELEPHONE: 702-435-8412

COMMENTS: Charles, Confirming our conversation, pls review and call if questions.

FROM:

Regards, TRG

Marketing & Sales Support

Building 14-4 Erie, PA

Facsimile No. (814) 875-6250, [redacted]

NAME: Tom Gerbracht

TELEPHONE: 814-875-3967

NUMBER OF PAGES: 4

IN CASE OF DIFFICULTY CONTACT:

DEBBIE LONG (814) 875-5689, 8*349-5689

April 12, 1996

Mr. Charles C. DeWeese
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Suite 102A
Las Vegas, Nevada 89121

Dear Charles,

We have conducted a preliminary analysis of your letter of February 15, 1996, to address your specific questions, and also to provide additional comments.

Your specific questions and our preliminary responses are as follows:

1. **Are there any fatal flaws in the power pack concept?**

   In our assessment, the response to this question is dependent on the manner in which the power pack concept is executed, and also in the way that the powerpacks would be used from an operations point of view.

   We suspect but have not confirmed that the total procurement cost of separate powerpacks would closely approach the procurement cost of new dual mode locomotives for JPB service, as power packs would be an all new design with considerable engineering required.

   There are additional issues we see with the use of a power pack concept. For example, we do not favor the transmission of high voltages of the type which would be required between the power pack and the diesel electric, using MU or inter-unit type cabling, and we are aware that the railroad industry has "standardized" on electric locomotive and Multiple unit car design wherein high voltages are "within" the power unit carbody and with appropriate protection to personnel. Specifically, we would discourage the use of connector type arrangements, even "permanent ones", at or near ground or carbody walkway level where they may be subject to vandals and trespassers, and would be a hazard to railroad operations personnel. Maintenance personnel who work on diesel electrics would also require warning and protection from the high voltages which could exist on the diesel electric, even if it were shut down, if the DE would be connected to an electric power pack.

   From a design standpoint, we believe that considerable power conditioning/conversion equipment may be required to suitably protect the alternator and/or motors of a diesel-electric locomotive which was originally designed to operate at much lower voltages, and we are aware that these locomotives and their insulation systems have aged. At the voltage and power level where the scheme might be economically attractive, diesel

electric performance might have to be reduced to assure that traction motors do not fail, etc.

2. **If the power pack were operational in the JPB fleet of 20 locomotives (15 trainsets required for weekday service) what would be the problems, and how would those problems affect service reliability and operating cost?**

   Some of the potential issues are addressed in Question 1. The use of powerpacks could result in reduced overall efficiency of the combined power unit(s), with higher operating costs for electric power. There would also be an adverse impact on maintenance costs, due to the use of a second "unit". Since the diesel electric locomotives you would propose to use are not microprocessor locomotives, the DE locomotive and the power pack would not have diagnostic capability as a maintenance aid.

   There would be reduced flexibility and a reduction in reliability due to the use of two power units which are interdependent, for example, if the power pack or the diesel electric were out of service for any reason. Obviously, this diesel locomotive model was not designed to work in this manner.

3. **Is this something GE is interested in being involved with? What do you estimate the order of magnitude costs for putting 20 power packs into service?**

   Since we have not undertaken any concept or design reviews which would be required to adequately address the issues raised in question 1, we cannot answer this question at this time. We would like to be kept informed as JPB plans develop.

4. **Is there a better answer (better being defined as cheaper, or possibly more reliable) than what has been conceptualized?**

   The use of a dual mode locomotive would address all of the issues identified above. While a dual mode locomotive with both diesel-electric and electric catenary capability does not now exist, it may be possible to package such a locomotive which would meet the JPB performance requirements, and which would address the safety, operating, and maintenance issues which a power pack would have.

   We are sure you are aware that the use of catenary would require significantly greater clearance over the top of the locomotive compared with a third rail DC system. The need for this greater tunnel and underground height would increase the total civil engineering costs for this project significantly for that portion of the route which is either underground or must pass beneath overhead structures such as bridges and overpasses in electrified territory.

5. **What modifications would be necessary for the F40 to work with the power pack. Would it be best to do them during an "ordinary" overhaul?**

Since we did not manufacture this locomotive, we are not qualified to identify all potential issues necessary to respond to this question. We do believe that any modifications would be best performed during an ordinary overhaul. We believe that the age of this basic engine and control technology, and the age of the locomotives themselves, would make the required modifications difficult to achieve in a cost effective manner. We are aware that some of the componentry is capable of being upgraded for reduced emissions, etc., but there appear to be space limitations in the locomotive design which would make the inclusion of modifications difficult, and would hinder access for maintenance. We are aware that the builder of this model has a succeeding model which is generally proposed, and both major builders have developed and introduced new technology into the marketplace since these locomotives were manufactured. If this assessment is correct, and we believe it is, a more suitable approach to this procurement might be to either sell the existing locomotives to a commuter "startup" operation as used power, or sell the locomotives on the used equipment market for parts.

We appreciate your letter and these questions, and we would like to be kept informed as this project develops.

Sincerely,

T.R. Gerbracht

T. R. Gerbracht
GE Transportation Systems
2901 East lake Road14-4
Erie, Pa. 16531
(814) 875-3967

c. R. Koontz 14-4

Appendix 4

Summary of conversation 4/10/96 with Jerry Pinkepank (206) 324 4650

Jerry is an independent consultant based in Seattle. He formerly was Director of Industrial Engineering for CB&Q. He says that he and I met in St. Louis in the early '70's.

He quickly understood the power pak concept. He suggested that used electric locomotives might be more easily modified.

✓ E-60 locomotives only had problems above 90 mph.

NJT has some. (6)

✓ The power pak concept is a rectifier tender.

A serious candidate for the power pak concept car body would be the Amtrak mail and express car, since it has a passenger truck and a short body. Other viable candidates would include head end and outfit cars from class one railroads, and troop sleepers, such as those that were stored at Hill Air Force Base near Ogden. The military tended to maintain railroad equipment well.

Current electric operations in the US include the Black Mesa and Lake Powell in northern Arizona, and Muskingham Electric in southeastern Ohio.

There were significant advances in electric locomotive technology between 1959 and 1963.

Wilmington was the only significant electric shop for Penn Central, Conrail, and Amtrak

Appendix 5

Summary of conversation 4/11/96 with Ved Wadwha, NJT (201) 955 5942

straight electric (25KV AC)

Ved immediately understood the concept, and commented on NJT's purchase of 32 ABB AEM-7 locomotives at $4 million each. (loco?)

He is traveling to Sweden next week (4/15/96) and will discuss the power pak concept with ABB.

✓ He feels it is very safe to assume that the power pak concept can be achieved within $1.5 million per unit. He commented that the cost of a traction power truck was $450,000. ✓

✓ He suggested I talk with Dave Carter, Director Capital Projects, Locomotive, for NJT at (201) 491 7738,

Appendix 6

Summary of conversation 4/11/96 with Dave Carter, NJT (201) 491 7738

NJT has 6 E-60's that are out of service, and available.

NJT has 12 ALP-44, is at a cost of $4.5 to $5 million. ✓

Carter thinks that a dual mode 750 volt GE Genesis II dual mode locomotive is a better option. ✓

✓The fuel carried in a dual mode locomotive was of concern to the fire department in dealing with Metro North in Grand Central Station. He suggested contacting Chris Damergis of Metro North at 914 271 0438 for more details.

Amtrak (with NJT) prepared a comprehensive System Safety Plan for high speed operation of trains in the Northeast Corridor.

✓He observed that Swedish catenary was of much simpler design than U. S. (he was referencing the electrification of the New York and Long Branch) and the Swedish trains run faster.

Appendix 7

Summary of conversation 4/11/96 with Dick Bates, AEP (614) 962 2013

Dick is a supervisor with American Electric Power in Ohio, about 80 miles southeast of Columbus. AEP operates a coal mine directly feeding a power generation plant. Muskingham Electric was a fully-automated electric railroad operating 15 miles to move the coal to the power plant. Changes in pollution laws have reduced the operation to 4 miles, with 2 locomotives, and manual operation. He was not sure what had happened to the other locomotives.

✓ When the power pak concept was explained, he viewed it as a "no sweat" operation, since the 200 ton trucks that move coal from the mines have electric motors on the wheels, are powered by diesel, and use pantographs mounted on the roof to reach catenary to run the trucks deep in mines where diesel operation is not possible. He suggested that Dresser Industries in Peoria, Illinois supply the trucks, or may lead to more knowledge. He had two names from old business cards

Larry Meyer, 309 672 7385, a parts person, and
Thomas N. Coyne, Manager Export Marketing, Haulback Division, 309 672 7720

He viewed the concept as not a big hassle, with the right people.

✓ He also mentioned Texas Utilities, in east Texas, and the Black Mesa and Lake Powell in northern Arizona, as other electric railroad operations.

DE LEUW, CATHER A PARSONS TRANSPORTATION GROUP COMPANY

De Leuw, Cather & Company
3075 East Flamingo Road, Suite 102A • Las Vegas, Nevada 89121 • (702) 435-7951 • Fax: (702) 435-8412

Include one copy of this letter AS AN example.

April 23, 1996

Mr. Terence A. Monaghan
VP Sales, Marketing and Customer Support
MK Rail Corporation
1200 Reedsdale Street
Pittsburgh, PA 15233

Dear Sir:

Attached is a single sheet describing the process leading to the "power pack" approach to a dual locomotive capability for the Joint Powers Board Peninsula Commute Service. It appears that the use of the power pack could allow electrification to proceed incrementally, avoid big-budget stalls, and allow the existing F-40 locomotive fleet to be used effectively. We will appreciate input from you on the concept. Specific questions, surely not all questions, follow:

1. Are there any fatal flaws in the power pack concept?

2. If the power pack were operational in the JPB fleet of 20 locomotives (15 trainsets required for weekday service) what would be the problems, and how would those problems affect service reliability and operating cost?

3. Is this something you are interested in being involved with? What do you estimate the order of magnitude costs for putting 20 power packs into service?

4. Is there a better answer (better being defined as cheaper, or possibly more reliable) than what has been conceptualized?

5. What modifications would be necessary for the F-40 to work with the power pack. Would it be best to do them during an "ordinary" overhaul?

There may or may not be potential applicability of the power pack concept to other operations. If one power pack could supply traction power for several diesel-electric units with the prime movers shut down, the applicability might extend to the oft-discussed Southern California electrification, or to other areas where air quality non-attainment is an issue.

I will certainly appreciate your comments on the concept, any alternatives that you think appropriate to address the San Francisco commuter extension, and your observations on any significant points not covered in the few questions above. Please call me at (702) 435 7951 with questions or comments.

Sincerely,

C. C. DeWeese

Charles C. DeWeese
Principal Railroad Project Manager

PARSONS

Caltrain Extension - Electrification Locomotive Concepts

1. When the extension of Caltrain to a new, downtown terminal station location is completed, trains will operate over one mile in tunnel. The station platforms will be below grade.

   - o Electric operation is required. No diesel operation in the tunnel is allowed Alternative fuel concepts are not acceptable.
   - o Budget constraints (at least) make initiating electric operation on the entire line at the same time impossible.
   - o Electric operation at 25,000 volts, AC, is required. Third rail is not acceptable.

2. Obviously, what is needed is a dual mode (diesel-electric and 25 kv AC) locomotive. Such a single unit does not exist. Analytic findings to date include:

   - o Retrofiting the F-40's is not possible due to space within the carbody.
   - o Purchase of a fleet of new, dual mode, locomotives, or a fleet of electric locomotives to mu with the F-40's is deemed not possible because of budget constraints.
   - o The apparent "best" solution is a "slug" locomotive unit, "power pack" to carry a pantograph and transform current from the overhead to be used by the F-40.

3. The F-40 would remain the controlling locomotive, and the pair, the F-40 and the power pack, would remain coupled in all normal service. When operating from the 25 kv catenary, the diesel prime mover would be shut down. The transition between the two sources should be transparent to the customers, and occur while moving. Conceptually, it is envisioned that

   - o The F-40 head end power (HEP) and air compressor would be electrically powered from either the F-40 prime mover, or the power pack, as appropriate.
   - o The F-40 could operate without the power pack coupled.
   - o The traction motors of the power pack and the traction motors of the F-40 would both operate in the electric mode. (Early analysis indicated that the maximum train size with one F-40 on the design grade, 3%, was 6 or 7 cars. The design train size is 10 cars.)
   - o The power pack would have no controls or independent operating capability.
   - o The required additional control functions (e.g. pantograph control, shutting the diesel down inbound and starting it outbound, with appropriate alarm lights) would be trainlined for control from the cab car as well as the F-40 cab.
   - o Modifications to the F-40 to accomodate this revised operation would be carried out during a planned F-40 overhaul.

Files, 4.12

ICF KAISER
ICF KAISER ENGINEERS GROUP

EDA, Incorporated
8300 Colesville Road, Suite 100
Silver Spring, MD 20910-3243
301/589-1988 Fax 301/589-2942

May 7, 1996

Mr. David Minster, P.E.
ICF Kaiser Engineers, Inc.
1800 Harrison Street
Oakland, CA 94612-3430

Subject: **CALTRAIN S.F. DOWNTOWN EXTENSION PROJECT-DUAL POWER LOCOMOTIVE OPTIONS, EVALUATIONS AND COST ESTIMATES**

Dear David:

Our comments on your April 19, 1996 letter to Mr. Charles C. DeWeese of DeLeuw, Cather & Company as well the DeLeuw, Cather & Company report on the subject with attachments are as follows:

1. Although changing or adding an electric locomotive at the north end of tunnel No.1 is possible, the delay incurred to add or remove a locomotive from a train will probably exceed the 5-10 minutes allowed. Amtrak allows 20-30 minutes to change engines in the Northeast Corridor. From direct observation, the Amtrak time is realistic. The time to add/remove a locomotive will not significantly differ from the time to replace a locomotive.

2. We do not recommend a dual mode diesel/25 kV locomotive with standard DC traction based on an F40 locomotive. The length of a dual mode diesel/25 kV locomotive will increase from 56 feet for an F40 to over 70 feet with a corresponding weight increase to 350,000 pounds or more. A transformer accounts for most of the additional length and weight. It is not recommended stretching an F40 more than 48" without additional major structural changes. A 4,000 HP diesel and triple axle trucks would be required to ensure equivalent F40 performance and compensate for the additional weight. Even if such a locomotive were available, sharp curve restrictions may not allow passage for this locomotive through your tunnels. For comparison, the GE dual-mode P32 AC-DM Genesis is a four (4) axle, 69 foot long, 264,000 lbs locomotive.

3. CalTrain should reconsider using a dual-mode diesel/DC electric locomotive using AC traction equipment for propulsion. Performance of AC traction has proved superior to F40 (with DC traction) performance at lower operating speeds such as those found in tunnels. General Electric has provided 10 dual-mode P32 AC-DM units (Genesis) operating from 750 V DC 3rd rail for Amtrak. EMD is developing an equivalent dual mode unit for Long Island Rail Road. Conversion costs to allow these units to operate for a 1,500 V DC or 3,000 V DC catenary should not be significant. In addition, a dual-mode diesel/DC electric locomotive would have market value for use either in dual mode or straight diesel operation.

4. A power pack "slug" unit operating from a 25 kV AC catenary using DC traction technology and built on an F40 or F32 chassis is technically viable. Depending on the performance desired, a power pack "slug" unit would approach an AEM7 electric locomotive in complexity and would weigh approximately 200,000 lbs. Train weight for an F40 PH-2 locomotive, a powered pack "slug" and seven (7) fully loaded cars is estimated at 1,600,000 lbs. Tractive effort required to move this train on a 2.7% grade with a balance speed of about 10 mph is 47,100 lbf. An F40 can only produce about 45,000 lbf of tractive effort at this speed. To achieve a speed of 20 mph through the tunnel, two axles on the "slug" would have to be powered to increase the available tractive effort. In addition, top speed of the train when running on straight diesel would be reduced by the additional train weight. A rough calculation shows that the maximum balance speed on level track will be less than 70 mph.

5. We concur with the other correspondents that acquisition costs of a powered "slug" using DC traction will approach the cost of a dual-mode locomotive at $4.4 million. Material costs alone for a transformer and traction control equipment are estimated at over $ 2.2 million (traction motors, acquisition and overhaul of an F40 or F32 locomotive, and current collection equipment are not included). At this time, there is no known source of used power conversion and traction control equipment suitable for use with a 25 kV AC catenary system.

6. As stated earlier, the performance curves of AC traction is considerably better than DC traction, especially at the critical lower tunnel speeds (AC tractive effort curve is flat up to the speed of 16 mph, while the DC traction curve significantly drops after 6 mph speed). The performance advantage of AC Traction will allow a lighter unpowered "slug" with an estimated weight of 90,000-110,000 lbs to be used. The train weight reduction and improved AC traction performance characteristics should allow the train to achieve 20 mph through your tunnel on a 2.7% rail grade. In addition, high speed train performance will not be compromised. Our rough calculations show that the maximum balance speed on level track will be over 75 mph.

7. Should CalTrain desire to continue with a power pack concept using a 25 kV AC catenary system, we recommend that they either convert their F40 PH-2 locomotives to AC traction at overhaul or purchase new diesel locomotives with AC traction to operate with an unpowered "slug" through the tunnels. The "slug" would convert 25 kV AC to a DC bus voltage usable by the locomotive inverters. DC bus voltage would be fed from the "slug", at roof level, to the locomotive bus. All train and traction functions will be retained by the locomotive. The equipment on the "slug" would be limited to current collection, a transformer, rectifier, smoothing reactor, auxiliary functions and HEP. We believe conversion costs for an F40 to AC traction and the acquisition of an unpowered power conversion "slug" to be equivalent to the acquisition of a powered "slug" using DC traction, i.e. $ 4.4 million per locomotive power unit.

In conclusion, considering the **power pack concept**, the AC traction has major performance advantages over DC traction in addition to reduced maintenance costs. The DC traction has only marginal acceptable performance characteristics for your application. The AC traction will satisfy your performance requirements with a comfortable margin of safety. The estimated cost for the power pack concept (either DC or AC) is about $ 4.4 million per power unit. The major benefit of the 25 kV AC power pack concept is in the continuous operation of the railroad as 25 kV AC catenary electrification progresses. On the other hand, while extending usefulness in the CalTrain operation it will have little if any market value anywhere else.

Regarding the **existing dual-mode locomotive (1,500 V DC)** we concur with LTK's statement that the P32 AC-DM (Genesis) and EMD equivalent are attractive for CalTrain. First, they can meet all requirements and minimize maintenance costs, and second they will have market value when the electrification program is complete. Taking into account that the existing CalTrain F40s would become surplus if new existing dual-mode locomotives were purchased, and there is a market for those locomotives ($ 1 million estimate for each locomotive), the dual-mode locomotives are the cheapest solution (considering the purchase costs of the new existing dual-mode locomotive of $ 4-4.5 million per unit). The disadvantage of the dual-mode locomotive (GE or EMD) approach is the need to sell the existing F40s fleet, purchase new dual-mode locomotives which will be obsolete once the whole 25 kV AC catenary electrification project is complete. In addition, CalTrain will not be able to take full advantage of the electric mode of the existing dual-mode locomotives unless the 1,500 V DC catenary is used. On "D" day the power station required for the 1,500 V DC catenary will have to be replaced with a 25 kV AC power station. The existing dual-mode locomotives will have to be replaced with the new 25 kV AC electric locomotives.

We do not recommend the development of a **new dual-mode locomotive using 25 kV AC catenary**. The step-down main transformer and associate equipment will make such a locomotive extremely heavy and long; heavier than 350,000 lbs. The required triple axle trucks will not be able to negotiate the tunnels sharp curves. We believe that the price of such a locomotive will be in the range of $ 5.5-6.0 million due to the high equipment and R&D costs accompanied with the low number of purchased locomotives.

If you have any questions or need further information or assistance, do not hesitate to contact me, Radovan, Jack or Al. If more detailed calculation and analysis is required we will be more than happy to assist you.

Very Truly Yours,

Paul G. Eiben
Director of Engineering

cc: Jack Barnas, P.E., ICF Kaiser Engineers Inc.
Radovan Sarunac, Ph.D., ICF Kaiser Engineers Inc.
Alan R. Zubor, ICF Kaiser Engineers Inc.

APPENDIX D

CALTRAIN SAN FRANCISCO DOWNTOWN EXTENSION PROJECT LOCOMOTIVE EMISSIONS TECHNOLOGY ANALYSIS

PREPARED FOR

PENINSULA CORRIDOR JOINT POWERS BOARD

Prepared by

SOUTHWEST RESEARCH INSTITUTE

UNDER SUBCONTRACT TO
ICF KAISER ENGINEERS, INC
OAKLAND, CAL

Issued
January, 1997

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1.0 INTRODUCTION

An extension of a CalTrain passenger train line is being considered for downtown San Francisco. The extension planned is underground. The overall purpose of the program is to determine optimum street alignment, underground station site location, number of tracks keeping future expansion in mind, tunneling method, etc.

The cost of electrification is high, about $230 million including the cost of replacing the entire diesel locomotive fleet. Therefore, it is desirable to use the existing internal combustion engine (diesel or alternate fuel) locomotive fleet. One task involves evaluating the feasibility of an underground passenger station from the point of view of health, safety, and odor concerns. The emissions and cost of diesel (or alternate fuel) locomotive fleets needs to be determined and compared with the cost of electrification.

2.0 PURPOSE

The purpose of this project is to determine if a fossil-fueled locomotive fleet can be made to work in an underground passenger station environment. The scope of work is focussed on the existing fleet of 20 General Motors Electro-motive Division (EMD) F40PH passenger locomotives and involves:

- Estimating emissions levels of current state-of-the-art diesel locomotives;
- Assessing applicability of low emissions retrofit technology to the existing fleet of diesel locomotives and estimating emissions levels with this technology;
- Estimating emissions levels of advanced low emissions alternate fuel (liquefied natural gas) locomotives; and
- Estimating the cost of retrofitting the existing fleet to run on liquefied natural gas and the cost of operating and maintaining natural gas locomotives.

3.0 CURRENT DIESEL LOCOMOTIVE EMISSIONS

3.1 GAS AND PARTICULATE EMISSIONS

Regulatory pressure on locomotives is increasing because they contribute as much as 8 percent of the NO_x (oxides of nitrogen) burden in Southern California (3.1). In the Bay Area, locomotives contribute only 2.2 percent of the NO_x. While this represents a small fraction of the total NO_x burden, the fact remains that locomotive emissions have been largely unregulated to date and some reductions may be possible. However, the focus of the current project goes beyond outdoor air pollution. The current project is concerned with the use of diesel-powered locomotives in an underground tunnel and passenger station in a heavily populated downtown environment. Therefore, in addition to contribution to environmental NO_x, the focus is on ventilation to be provided in the tunnel/ underground station to avoid exposure to high concentrations of NO_x and PM

(particulate matter). Concentrations of hydrocarbons (HC), carbon monoxide (CO), and sulfer dioxide (SO_2) also were considered. The situation is similar to that in underground mines. It may be possible to determine the allowable human exposure to NO_x concentrations from underground mining practice (3.2).

Data on current F40PH locomotive engine emissions (or any other locomotive engines) are not as extensive as data on truck diesel engines. Very little public domain data could be accessed. Table 1 presents data from an EMD 12-645E3B engine which is used in the existing F40PH locomotives (3.3).

TABLE 1: DATA FROM EMD 12-645E3B ENGINE

Diesel Engine: 12-645E3B								
Throttle	BHP	FUEL CONS. lbm/hr	BSFC lbm/bhp-hr	HC g/hr	CO g/hr	NO_x g/hr	SO_x g/hr	PM g/hr
Low Idle	0.0	18.7	--	79.1	286.0	571.3	55.9	24.5
DB-1	11.4	27.5	2.41	102.8	349.3	891.2	82.2	23.7
DB-4	36.4	75.2	2.07	225.8	528.2	2020.5	224.9	52.8
Notch-1	111.7	54.5	0.49	90.7	205.4	1900.8	163.0	20.0
Notch-2	417.0	159.0	0.38	147.0	348.5	5270.6	475.5	126.9
Notch-3	593.8	222.7	0.38	203.6	313.6	7859.1	666.0	183.9
Notch-4	877.9	324.4	0.37	247.0	337.8	10705.5	970.2	207.4
Notch-5	1104.8	404.2	0.37	316.1	376.1	13145.0	1208.9	243.7
Notch-6	1517.6	548.7	0.36	367.2	718.3	17955.9	1641.0	404.3
Notch-7	2103.3	748.5	0.36	427.2	921.9	23563.3	2238.6	488.0
Notch-8	2451.3	871.7	0.36	545.9	915.4	27885.8	2607.1	619.4

The data for Table 1 relates to one diesel locomotive model which may not be representative of the fleet of existing F40PH locomotive engines. In order to get a better estimate of emissions for the existing CalTrain locomotive fleet, additional data are presented, although in one case the number of conditions is limited, and in the other, data are from a similar (but not the same) engine model.

Table 2 presents data from an in-use F40PH locomotive (3.4). The data were obtained at a limited number of engine conditions, specifically at three notch positions rather than at all eight. In locomotive terminology, a "notch position" represents a power level or throttle position. Notch-8 represents full power condition. To further supplement the limited data, Table 3 is presented.

TABLE 2: EMD F40PH EMISSION TEST RESULTS (NON-HEAD END POWER MODE)

<table>
<tr><th colspan="7">Standard Timing Baseline Tests = 11-19-93</th></tr>
<tr><th></th><th>Estimated Flywheel Observed BHP</th><th>Fuel Rate (lb/hr)</th><th>HC (g/hr)</th><th>CO (g/hr)</th><th>Corr. Dry NO_x (g/hr)</th><th>Part. (g/hr)</th></tr>
<tr><td colspan="7">Notch 8 (Full Power)</td></tr>
<tr><td>Run #1</td><td>2,723</td><td>1,010.4</td><td>580</td><td>956</td><td>33,853</td><td>754</td></tr>
<tr><td>Run #2</td><td>2,707</td><td>1,004.4</td><td>621</td><td>950</td><td>33,849</td><td>662</td></tr>
<tr><td>Run #3</td><td>2,711</td><td>1,005.6</td><td>621</td><td>900</td><td>33,293</td><td>707</td></tr>
<tr><td>Average</td><td>2,714</td><td>1,006.8</td><td>607</td><td>935</td><td>33,665</td><td>707</td></tr>
<tr><td>Cov percent</td><td>0.3</td><td>0.3</td><td>3.9</td><td>3.3</td><td>1.0</td><td>6.5</td></tr>
<tr><td colspan="7">Notch 5 (Mid-power)</td></tr>
<tr><td>Run #1</td><td>1,334</td><td>507.0</td><td>349</td><td>805</td><td>13,587</td><td>435</td></tr>
<tr><td>Run #2</td><td>1,329</td><td>505.2</td><td>347</td><td>831</td><td>13,129</td><td>396</td></tr>
<tr><td>Run #3</td><td>1,320</td><td>501.6</td><td>340</td><td>732</td><td>13,313</td><td>395</td></tr>
<tr><td>Average</td><td>1,328</td><td>504.6</td><td>345</td><td>789</td><td>13,343</td><td>409</td></tr>
<tr><td>Cov percent</td><td>0.5</td><td>0.5</td><td>1.4</td><td>6.5</td><td>1.7</td><td>5.5</td></tr>
<tr><td colspan="7">Idle</td></tr>
<tr><td>Run #1</td><td>20</td><td>23.4</td><td>84</td><td>151</td><td>756</td><td>15</td></tr>
<tr><td>Run #2</td><td>20</td><td>24.0</td><td>80</td><td>150</td><td>752</td><td>15</td></tr>
<tr><td>Run #3</td><td>20</td><td>23.4</td><td>77</td><td>151</td><td>731</td><td>Void</td></tr>
<tr><td>Average</td><td>20</td><td>23.6</td><td>80</td><td>151</td><td>746</td><td>15</td></tr>
<tr><td>Cov percent</td><td>0.0</td><td>1.5</td><td>4.4</td><td>0.4</td><td>1.8</td><td>2.4</td></tr>
<tr><td colspan="7">Standard Timing -- AAR 3-Mode Weighted</td></tr>
<tr><td></td><td></td><td>obs. SFC (lb/hp-hr)</td><td>HC (g/hp-hr)</td><td>CO (g/hp-hr)</td><td>Corr NO_x (g/hp-hr)</td><td>Part. (g/hp-hr)</td></tr>
<tr><td></td><td>Run #1</td><td>0.382</td><td>0.27</td><td>0.50</td><td>11.95</td><td>0.30</td></tr>
<tr><td></td><td>Run #2</td><td>0.382</td><td>0.28</td><td>0.51</td><td>11.89</td><td>0.27</td></tr>
<tr><td></td><td>Run #3</td><td>0.382</td><td>0.27</td><td>0.48</td><td>11.81</td><td>0.27</td></tr>
<tr><td></td><td>Average</td><td>0.362</td><td>0.27</td><td>0.50</td><td>11.88</td><td>0.28</td></tr>
<tr><td></td><td>Cov percent</td><td>0.1</td><td>1.7</td><td>3.8</td><td>0.6</td><td>5.9</td></tr>
</table>

TABLE 3: EMD 12-710 G3A ENGINE MASS EMISSION RATE SUMMARY

Standard Injection Timing Test Date = 5/12/92

Notch	Hydrocarbon (g/hr)	Carbon Monoxide (g/hr)	Oxides of Nitrogen (g/hr)	Particulate (g/hr)	Sulfur Dioxide (g/hr)	BHP
8	895	3663	38,808	670	221.8	3210
7	557	1869	25,452	440	173.8	2540
6	384	663	17,390	291	119.3	1700
5	359	614	14,851	261	100.2	1390
4	289	277	12,751	190	76.7	1060
3	232	192	10,675	135	53.1	714
2	148	208	5,987	54	29.5	370
1	114	153	3,475	30	19.0	207
High Idle	93	78	1,147	24	6.8	14
Low Idle	35	36	596	8	2.9	10
DB-4	239	217	2,243	88	16.5	28

It is seen that data in Table 3 were obtained on an F59PH locomotive which uses an EMD 12-710G3A engine (3.5). However, this engine is very similar to those in the existing CalTrain fleet of F40PH locomotives. The two engines have the same bore and stroke. The only difference is that one is a 16-cylinder engine and the other is a 12-cylinder engine. Hence, the power level and mass emissions rate of the two engines are different by a factor of 16/12. Examining the data on a g/hp-hr basis, or dividing the mass emissions rate (g/hr) in Table 3 by a factor of 16/12, should give values that can be directly compared.

Comparison of the data in the three tables shows a fair amount of consistency (when adjusted for displacement (i.e., number of cylinders) and increases the confidence level that the locomotive emissions data are representative. Therefore, Table 1 can be used for estimating CalTrain diesel locomotive ventilation requirements.

In addition to the main propulsion engine, the locomotive also has a "Head End Power" engine which supplies electric power for lighting, heating, and air conditioning to the passenger cars. In F40PH locomotives, separate, small DDC 8V-149TA engines are used for this purpose. Table 4 gives emissions data for this engine. These data should also be used when making total locomotive emissions estimates and ventilation requirement estimates in the underground station.

TABLE 4: EMISSIONS DATA ON THE DDC 8V-149TA ENGINE

Diesel Engine: DDC 8V-149TA, ESTIMATED								
Load Percent	bhp	FUEL CON. lbm/hr	BSFC lbm/bhp-hr	HC g/hr	CO g/hr	NO_x g/hr	SO_x g/hr	PM g/hr
0	0	0.0	0.56	0.0	0.0	0.0	0.0	0.0
25	195	76.1	0.39	175.5	409.5	2028.0	34.5	39.0
50	390	136.5	0.35	234.0	273.0	3705.0	61.9	39.0
75	585	193.1	0.33	292.5	351.0	5265.0	87.6	58.5
100	780	257.4	0.33	312.0	624.0	7332.0	116.8	156.0

3.2 DIESEL ODOR

Extensive study of diesel engine odor occurred about 20 years ago when diesel engines were projected to gain up to 25 percent of the passenger car market. Diesel odor was characterized as "oily"and "smoky burnt". Testing to determine a person's threshold of tolerance of diesel odor was performed using truck diesel engines (3.6,3.7,3.8). However, data related to these studies was never published.

Because of the potential low tolerance level of passengers to diesel odor in an underground station environment, ventilation requirements may be determined more by passenger objection to odor than by NO_x levels. Additional research on human tolerance of diesel odors needs to be conducted either on locomotive engines or by making a conservative extrapolation from truck diesel engines. Testing of a flow-through catalyst in the exhaust system to **reduce or eliminate** diesel odor should also be examined. These studies are beyond the scope of this technical report.

4.0 ADVANCED LOW EMISSION DIESEL LOCOMOTIVES

In the early 1970's, uncontrolled truck diesel engine NO_x emissions were approximately 16 g/hp-hr (4.1). Emissions control technology for NO_x, HC, and PM has made considerable advances during the past twenty years. Current truck diesel engine NO_x emissions levels have been reduced to 5 g/hp-hr (4.1). In addition, the Engine Manufacturers Association and the federal Environmental Protection Agency (EPA) have signed a "Statement of Principles" agreeing to further stringent standards on the order of 2 g/hp-hr NO_x by 2004 (4.2). Some of this technology may be applicable to locomotive diesel engines. However, given the historical "lag" between on-highway truck engine technology and locomotive engine technology, ventilation calculations should probably be based on a level of 8 g/hp-hr.

Data on emissions control technology for locomotive engines are not available in the literature. Very limited data on the effect of low aromatic fuel, timing retard, and improved aftercooling are available. Table 5 indicates the effect of injection timing retard on levels of PM, HC, CO, and NO_x. The table shows that NO_x reductions of 15 percent are possible by retarding injection timing by 4^o crank angle (4.3). Note that this also increases fuel consumption by 1.3 percent.

TABLE 5: EFFECT OF INJECTION TIMING RETARD
EMD 12-645E3B, BASELINE FUEL

	BSPM g/bhp-hr	BSHC g/bhp-hr	BSCO g/bhp-hr	$BSNO_x$ g/bhp-hr
Injection Timing Retard				
0° (Standard)	.15	.29	.81	10.46
2°	.25	.33	.77	9.49
4°	.24	.40	.85	8.89
6°	.25	.40	.95	8.04

Table 6 (4.3) indicates that improved aftercooling reduces NO_x. Improved aftercooling is used to its full benefit in on-highway truck engines. However, similar aftercooling effectiveness is not available on locomotives because of ram air limitations as well as frontal area limitations. Intake charge air temperature in on-highway truck diesel engines is on the order of 130 degrees F. However, in an EMD 12-645E3B engine, intake temperatures of 180 degrees F are more likely.

TABLE 6: AFTERCOOLING EFFECT ON EMD 12-645E3B
4° RETARDED TIMING, BASELINE FUEL

	BSPM	BSHC	BSCO	$BSNO_x$
Aftercooler Temperature, °F	g/bhp-hr			
210	.24	.40	.85	8.89
195	.25	.38	.95	8.12
180	.23	.38	.92	7.98
165	.23	.39	.93	7.88

A summary of the combined effects of injection timing retard, aftercooling, and low-aromatic fuel is presented in Table 7. **The tables indicate that a 30 percent reduction in NO_x is readily possible.** With improved injection and load control systems, further decreases in NO_x and PM emissions may be possible. While these and other improvements are possible, given the constraints of retrofit technology, **ventilation requirements should be based on an NO_x level of 8 g/hp-hr**.

TABLE 7: STAGES OF EMISSION REDUCTIONS
EMD 12-645E3B

	BSPM	BSHC	BSCO	$BSNO_x$
	g/bhp-hr			
Baseline	0.15	0.29	0.81	10.46
4° Retard	0.24	0.40	0.85	8.89
4° Retard 180°F Aftercooling	0.23	0.38	0.92	7.98
4° Retard 180° Aftercooling Low-Aromatic Fuel	0.19	0.33	1.02	7.18

5.0 NATURAL GAS LOCOMOTIVES

Natural gas is a plentiful domestic energy source. It is safely handled every day through pipelines and appliances. There are nearly 277,000 miles of main transmission pipelines at high pressure, 700-1000 pounds per square inch (psi), across the country. The pipelines traverse mainly open, sparsely populated spaces. The natural gas is transported as compressed natural gas (CNG). If liquefied natural gas (LNG) were selected as the propulsion system for CalTrain, LNG would be carried at a temperature of -200 degrees F at about 100 psi pressure. (The temperature of LNG is -270 degrees F at atmospheric pressure). The lower heating value of LNG under these conditions is approximately 76,100 Btu/gallon compared to 129,000 Btu/gallon for diesel fuel. **Therefore, 1.7 gallons of LNG have to be carried for every gallon of diesel fuel.**

In the application being considered for CalTrain, a Failure Mode and Effects Analysis (FMEA) would need to be done, particularly because LNG would be carried through underground (semi-enclosed) passages. One source of concern would be the potential for natural gas leaks or fuel tank ruptures. In the event of a leak or rupture, the accumulation of natural gas in "pockets" on the ceiling of a tunnel or an underground station could be possible. Natural gas is flammable and can be explosive, depending on the concentration. It is usually not possible to predict the exact conditions of explosions.

Locomotives, tunnels, and underground stations would need to be carefully designed to prevent and detect leaks if they occur (natural gas detectors are state-of-the-art). Because natural gas is much lighter than air and quickly rises, the accumulation of natural gas in "dead pockets" on the ceiling of tunnels or an underground station could be possible. Underground ventilation and electrical systems would need to be developed so that a natural gas leak would not ignite. In addition, emergency procedures for evacuating passengers and for redirecting locomotives into an open area would need to be developed. Such a safety analysis and development of design specifications is beyond the

scope of this report, but is essential before deciding to use LNG for CalTrain locomotive propulsion.

Natural gas use in mobile applications is increasing (5.1), particularly in response to the nation's increasing dependence on imported oil and regional air quality problems. Southwest Research Institute has developed more than 24 light duty and heavy duty engines to run on natural gas. Applications of these engines range from passenger cars, vans, delivery trucks, urban buses, and garbage trucks to long haul trucks. Data indicate that when the most advanced technology diesel engines are converted to natural gas, emission levels can be reduced by more than 50 percent.

Many vehicular applications today involve the use of CNG. CNG is stored on board in high pressure (3600 psi) gas cylinders. In this situation, refueling times are longer than desirable and vehicle range is not as long. There is a small but growing trend towards the use of LNG. Bus properties such as Houston Metro and national trucking companies such as Roadway have done pioneering work in implementing the use of LNG for their fleets (5.2).

Natural gas is also being used in locomotives. Burlington Northern railroad has converted two locomotives operating on a fixed route to run on LNG (5.3). These locomotives operate over long distances. In order to get the needed range with natural gas, a cryogenic LNG tender car towed behind the locomotive is used to carry the fuel. Union Pacific is reported to be experimenting with four switcher locomotives running on LNG in southern California (5.4). In this case, the switcher locomotives operate only in the yard. Since range is not an issue, LNG is carried in cryogenic tanks on-board the locomotive without the need for a separate tender car. The capacity of on-board cryogenic tanks on these switcher locomotives is reported (5.4) to be 1200 gallons of LNG (not diesel-equivalent gallons). With this size tank, the refueling interval for the locomotive may be an issue.

5.1 NATURAL GAS RETROFIT

The current project envisages the use of LNG in urban passenger locomotive application Although CalTrain has a limited range, long idle times in the station and head-end power would be required to provide service power to the passenger cars. The issue of how much fuel to carry on board can be addressed in two ways: 1) make minimum changes to the existing design, determine how much LNG can be carried, and then determine the range and refueling interval; or 2) determine an ideal refueling interval based on operations and calculate the size of the fuel tank needed. Both these approaches are discussed in the paragraphs below.

The capacity of current diesel fuel tanks is about 1800 gallons. If these were replaced with LNG tanks, the outer tank volume would remain the same. Vacuum jacketing and insulation would be required to carry cold (-200 degree F) LNG. Detailed tank designs for the specific size and shape are beyond the scope of this report. Therefore, only a

rough estimate of space requirements for insulation can be made, approximately 10 percent for the initial estimates. In addition, 20 percent volume has to be set aside for ullage (vapor) space above the liquid surface. Thus the total volume of LNG that can be carried in the current diesel fuel tank space would be only 1260 gallons, or about 740 diesel-equivalent gallons taking energy density and heating value differences into account. This fuel tank size would give the locomotive roughly a 200 to 240 mile range.

The other approach determines the locomotive's desired range and calculates the requisite fuel tank volume. For the operational convenience of refueling once a day, a minimum range of 400 miles for the locomotive is necessary; 500 miles is desirable. Current locomotives use three gallons of diesel fuel per mile, including all idling and head-end power needs (5.5). Therefore, it is necessary to have between 1200 and 1500 diesel-equivalent gallons of LNG on board. Using density, heating value, estimates of engine efficiency differences between natural gas and diesel fuel and allowing 20 percent ullage (vapor) space over the liquid surface, between 3000 and 3800 gallons of LNG would need to be stored. Further space needs are dictated by insulation requirements for cryogenic tanks. Current F40PH locomotives have tanks with 1800 gallon capacity. Therefore, more space has to be found on the locomotive than is currently available by replacing the diesel fuel tanks. A design feasibility study is required to see if and how 3000-3800 gallons of LNG tanks can be accommodated on the existing F40PH locomotives.

A significant design consideration is the engine itself. The Burlington Northern locomotive referred to above (5.3) has the same two-stroke EMD-645E3B engine as the F40PH locomotive. The technology used in this engine (5.6) may be available as a commercial retrofit kit from Energy Conversions, Inc. **This technology reduces full load NO_x emissions to about 3.6 g/hp-hr compared to uncontrolled levels of about 12 g/hp-hr, a 70 percent reduction in NO_x emissions**. However, under idle conditions, the Burlington Northern locomotive engine operates on diesel fuel alone. This implies that some small quantity of diesel fuel will have to be carried in addition to LNG. The quantity of diesel fuel to be carried cannot be exactly determined unless a more complete analysis of the duty cycle and idling times is done. However, it is unlikely that the quantity required will present any problems.

The cost of converting the locomotive to LNG operation is reported to be $280,000 (5.7). This cost includes the conversion kit ($230,000), additional aftercoolers ($3,200 each), cryogenic pumps and plumbing, and the installation. However, current EMD 12-645 chassis designs (F40PH) do not contain enough space to allow for the installation of cryogenic tanks, pumps, and vacuum insulation for 3800 gallons of LNG, even with the diesel fuel tanks removed. Therefore, LNG tenders may be required to accommodate enough fuel for the desired range.

More advanced natural gas locomotive engine technology is now under development at Southwest Research Institute under a cooperative research program called GasRail USA. However, results of this technology are not available in retrofit kit form at this time.

Engineering results from this project are likely to be available in 2 to 3 years time. Additional engineering development and production capability would be required before retrofit kits can be made available. Table 8 gives engineering estimates of the emissions levels that might be obtained using three different technologies being evaluated at SwRI: 1) dual fuel (natural gas plus diesel); 2) spark ignited 100 percent natural gas; and 3) late-cycle injection 100 percent natural gas engines. Table 8 indicates that considerable (80 percent) reductions in NO_x compared to the baseline diesel engine (refer to Table 1) are possible. This advanced technology can be easily retrofit (when it becomes available) to the presently available Energy Conversions, Inc. technology described above (5.6).

5.2 FUELING FACILITIES

Three significant issues need to be examined when considering refueling locomotives: 1) transporting LNG by truck to an on-site, large, LNG storage tank; 2) fueling the locomotives directly without a storage tank; and 3) transporting CNG via pipeline to an on-site liquefaction and storage tank.

LNG refueling is technically feasible. Several bus properties have LNG storage, handling, and refueling capabilities. Refueling out of a storage tank is routinely done at the Burlington Northern facility in Minnesota. The technology exists to refuel Burlington Northern locomotives (Air Products, Inc LNG tender, 28,000 gallons) in a 30-minute duration. This fueling rate of 1,000 gallons per minute would be more than sufficient to meet the refueling requirements of the current project. However, special training for personnel to handle cryogenic components at -200 degrees F would be required. Special equipment will be required to recover LNG vapor (unavoidable) during refueling.

The total fuel consumption of this project (based on 23 locomotives at 12,000 gallons of diesel fuel per locomotive per month) is 586,500 gallons of LNG per month (5.6) or about 20,000 gallons per day. LNG trucks normally are capable of delivering 10 to 12,000 gallons of LNG per truck. Thus, two truck loads daily could refuel the 23 locomotives directly from the trucks to the locomotives, obviating the requirement of a storage tank. LNG trucks could be equipped with advanced technology vapor recovery systems so that venting is minimized. Local regulations allowing LNG trucks to travel through the local geographic area and the location of the nearest LNG plant would need to be considered before this fueling system could be implemented. In addition, without on-site storage, the natural gas fuel supply for CalTrain would be completely dependent on "just in time" delivery.

Alternatively, an LNG storage tank could be installed at the CalTrain storage yard(s), subsequently relaxing the LNG delivery schedule. A 50,000 gallon capacity LNG storage tank would cost about $300,000 (5.8). Installation costs would be highly dependent on local and state building codes and regulations. Current costs for the complete installation of a 15,000 gallon LNG storage tank and refueling facility would be approximately

TABLE 8: ALTERNATIVE FUELED LOCOMOTIVES EMPLOYING VARIOUS NATURAL GAS COMBUSTION TECHNOLOGIES

Alternative Fueled Loco Employing Various Combustion Technologies

Engine: 12-710G3A — Dual Fuel

Throttle	BHP	FUEL CON. lbm/hr	BSFC lbm/bhp-hr	HC g/hr	CO g/hr	NOx g/hr	SOx g/hr	PM g/hr
Low Idle	6.63	60.1	9.06	2737.8	162.4	667.1	0.0	9.4
DB-1	10.455	40.6	3.88	3517.8	284.5	1059.8	0.0	14.8
DB-4	21.08	81.8	3.88	9535.6	685.2	2101.1	0.0	29.8
Notch-1	177.65	115.0	0.65	4180.0	338.6	2498.6	0.0	10.7
Notch-2	316.2	155.5	0.49	4092.0	379.4	4196.2	0.0	34.6
Notch-3	609.45	291.8	0.48	6094.5	559.3	7464.0	0.0	64.5
Notch-4	895.05	417.0	0.47	6844.5	916.1	9484.9	0.0	72.7
Notch-5	1191.7	555.2	0.47	8412.0	2565.7	11492.9	0.0	88.3
Notch-6	1441.6	671.6	0.47	9328.0	4223.0	13623.1	0.0	127.2
Notch-7	2155.6	976.4	0.45	11412.0	13009.7	17802.7	0.0	159.8
Notch-8	2716.6	1230.5	0.45	17578.0	11793.2	22795.5	0.0	220.5

Engine: 12-710G3A — 100% Natural Gas Dedicated

Throttle	BHP	FUEL CON. lbm/hr	BSFC lbm/bhp-hr	HC g/hr	CO g/hr	NOx g/hr	SOx g/hr	PM g/hr
Low Idle	5.46	65.0	11.90	2737.8	162.4	177.9	0.0	9.4
DB-1	8.61	43.9	5.10	3517.8	284.5	282.6	0.0	14.8
DB-4	17.36	88.5	5.10	9535.6	685.2	560.3	0.0	29.8
Notch-1	146.3	124.4	0.85	4180.0	338.6	666.3	0.0	10.7
Notch-2	260.4	168.2	0.65	4092.0	379.4	1119.0	0.0	34.6
Notch-3	501.9	315.7	0.63	6094.5	559.3	1990.4	0.0	64.5
Notch-4	737.1	451.1	0.61	6844.5	916.1	2529.3	0.0	72.7
Notch-5	981.4	600.6	0.61	8412.0	2565.7	3064.8	0.0	88.3
Notch-6	1187.2	726.6	0.61	9328.0	4223.0	3632.8	0.0	127.2
Notch-7	1775.2	1056.2	0.60	11412.0	13009.7	4747.4	0.0	159.8
Notch-8	2237.2	1331.1	0.60	17578.0	11793.2	6078.8	0.0	220.5

Engine: 12-710G3A — LaCHIP (Late Cycle High Pressure Injection)

Throttle	BHP	FUEL CON. lbm/hr	BSFC lbm/bhp-hr	HC g/hr	CO g/hr	NOx g/hr	SOx g/hr	PM g/hr
Low Idle	7.8	54.6	7.00	2737.8	162.4	444.7	0.0	9.4
DB-1	12.3	36.9	3.00	3517.8	284.5	706.5	0.0	14.8
DB-4	24.8	74.4	3.00	9535.6	685.2	1400.7	0.0	29.8
Notch-1	209	104.5	0.50	4180.0	338.6	1665.7	0.0	10.7
Notch-2	372	141.36	0.38	4092.0	379.4	2797.4	0.0	34.6
Notch-3	717	265.29	0.37	6094.5	559.3	4976.0	0.0	64.5
Notch-4	1053	379.08	0.36	6844.5	916.1	6323.3	0.0	72.7
Notch-5	1402	504.72	0.36	8412.0	2565.7	7661.9	0.0	88.3
Notch-6	1696	610.56	0.36	9328.0	4223.0	9082.1	0.0	127.2
Notch-7	2536	887.6	0.35	11412.0	13009.7	11868.5	0.0	159.8
Notch-8	3196	1118.6	0.35	17578.0	11793.2	15197.0	0.0	220.5

$300,000 (5.8). Annual operating and maintenance cost for such a facility would be about $75,000. **In addition, the cost of LNG is usually negotiated and is highly variable, depending on local conditions. A rough estimate of $0.32/gallon of LNG could be used.**

Another method of obtaining LNG is to use an existing gas pipeline as a source and to build a liquefaction plant on site. Although transportation of natural gas by pipeline would be very effective and LNG would be available on site, the cost of building such a plant would be high (approximately $15.4 million), particularly for the low volumes of LNG used on CalTrain. Additional operating costs of $350,000/year would be expected. Usually, such plants are only economical for very large volumes of LNG.

6.0 EVALUATION OF OPTIONS

In this section, capital and operating and maintenance costs for each option are estimated. Depending on which option(s) is selected, the relevant cost data can be used.

6.1 EXISTING DIESEL TECHNOLOGY

This option is considered as the baseline case. In principle, it may be possible to do nothing to the existing locomotive and use a large enough ventilation system to control the levels of pollutants in the underground passenger station and tunnel. Federal and state environmental regulations dealing with locomotives do not preclude the use of this option. However, local jurisdiction regulations, especially in an enclosed situation, may have to be considered separately. It is also possible that ventilation requirements would be dictated by passenger acceptance of odor. Diesel exhaust odor can be objectionable and a large volume of ventilation may be necessary in order to overcome this objection.

If the baseline diesel option were used, no additional capital costs would be incurred except for the design and construction of the ventilation system. Baseline emissions data are provided to make the necessary estimates (refer to Tables 1 through 4).

Fuel, maintenance, and insurance costs are a matter of record and should not differ from current experience. The cost of power to run the ventilation system would have to be considered.

6.2 LOW EMISSIONS DIESEL RETROFIT KIT

This option involves retrofitting the existing CalTrain diesel engines with low emissions retrofit kits. The data presented earlier in Tables 1 through 4 indicate that existing locomotive diesels emit approximately 12 g/hp-hr NO_x at full load. Data presented in Tables 5 and 6 indicate that advanced emissions control technology can reduce NO_x to a level of about 8.0 g/hp-hr, a 33 percent reduction. Further reductions may be possible by using on-highway truck diesel engine technology, but this is as yet unproven. In addition, significant differences between locomotive and truck diesel engines exist (notably

locomotive frontal area for intake charge cooling) that make it difficult to use on-highway truck diesel engine technology. Therefore, an estimate of 8.0 g/hp-hr should be used for ventilation calculations at this time. It is most prudent to use a 33 percent reduction in the data of Tables 1 through 4 for NO_x. Small reductions in other pollutants are possible. The effect on diesel exhaust odor is unknown.

The cost of a retrofit kit is nominal. Additional four-pass aftercoolers cost $3,200 each, and redesigned camshaft segments would be approximately $1,300 per segment. The EMD 12-645 requires two right segments and two left segments for each bank of cylinders. Thus, the total cost of a retrofit kit would be approximately $8,400 for a 30 percent reduction in NO_x. Improved controls on the governor may also aid in further decreasing other emissions. A certified kit is not available at this time.

The cost of development through certification may be high (about $6 million). However, formal EPA certification may not be needed since no legal (regulatory) requirement currently exists. Only ventilation may have to be considered. The cost of adopting advanced diesel emission control technology without certification requirements could be approximately $2 million for development work. Fuel, maintenance, and insurance costs would be unchanged compared to the baseline.

6.3 NATURAL GAS RETROFIT KIT

The technology represented by this option has been discussed in Section 5.0. Within this option, a couple of alternatives need to be considered.

Current ECI technology alternative is a dual-fuel design. A small (as yet undetermined) quantity of diesel fuel still has to be carried. Considerations of fuel tank size and locomotive range have already been discussed in some detail above. In this technology, LNG is used only at high loads. This reduces the bulk of the NO_x emissions. At light loads, LNG is not used. Emissions data for this technology over the complete locomotive notch position range is not available. Estimates can be made by using emissions values from Table 1 for Notch 1 through Notch 3. At higher notch levels, NO_x emissions data can be reduced by the ratio 3.6/12. This ratio is derived from Reference 5.6 which has data at full load only (Notch 8). It is generally acceptable to assume reductions in NO_x in the same ratio as at full load. Such a composite table of "data" is given in Table 9. However, because of the way in which this table was calculated, its validity is not assured.

The capital costs of conversion to this technology have already been noted - $280,000 per locomotive, including additional aftercoolers, cryogenic pumps, vacuum liners, plumbing, and installation. The cost of two fueling options has also been discussed:

- This option involves no storage tank; daily delivery maintaining a "just in time" schedule; and refueling at the surface rather than underground. No capital cost would be incurred for refueling, and fuel cost would be approximately $0.32 per gallon of LNG.

TABLE 9: COMPOSITE DATA FOR DUAL-FUEL LOCOMOTIVES

Engine: 12-645E3B				
Throttle	BHP	FUEL CON. lbm/hr	BSFC lbm/bhp-hr	NO_x g/hr
Notch-1	111.7	54.5	0.49	1900.8
Notch-2	417.0	159.0	0.38	5270.6
Notch-3	593.8	222.7	0.38	7859.1
Notch-4	877.9	324.4	0.37	3211.7
Notch-5	1104.8	404.2	0.37	3943.5
Notch-6	1517.6	548.7	0.36	5386.8
Notch-7	2103.3	748.5	0.36	7069.0
Notch-8	2451.3	871.7	0.36	8365.7

- A second option is to build a storage tank at $300,000 for 50,000 LNG gallon capacity and relax delivery schedules. This does not include installation costs. Installation costs are highly dependent on local and state building codes and pressure vessel regulations. Inspection and maintenance costs of the storage tank are expected to be $75,000 annually. There may be additional costs for the design and installation of gas detection equipment throughout the tunnel and underground station.

Operational and maintenance costs for this technology are estimated and compared to the baseline case. LNG cost is estimated to be $0.32/gallon. Since 1.7 gallons of LNG is equivalent to one gallon of diesel fuel, fuel costs are about $0.54 per diesel equivalent gallon. Therefore, a slight net savings in fuel costs compared to baseline fuel costs may occur.

Regular inspection and maintenance cost of the cryogenic pumps, fuel tanks, and locomotives are estimated to be $55,000/year per locomotive. In addition, there may be other costs such as training for personnel to handle LNG, additional insurance costs, and the cost of inspecting and maintaining gas detection equipment in the underground tunnel and station. Estimates of these costs are beyond the scope of this report.

6.4 ADVANCED NATURAL GAS ENGINES

More advanced technology is currently under development at SwRI under a program called GasRailUSA. Results of this technology are not yet available in a retrofit kit form. Engineering results might be available in two to three years. More time will be needed to do pre-production development and have the production facility in place. The conversion cost for this technology will probably be the same as that for the natural gas retrofit kit described above. It is expected that emissions levels will be considerably lower (estimated to be a further 50 percent reduction from the levels described in Table 8). It is

also expected that this technology can be readily adopted as a second step upgrade to the ECI technology described above at nominal cost.

7.0 CONCLUSIONS AND RECOMMENDATIONS

It appears to be technically feasible to operate existing diesel locomotives in an enclosed, underground environment and to keep pollutants at acceptable levels by using adequate ventilation. NO_x emission levels from current locomotives (about 12 g/hp-hr) would determine specific ventilation requirements. In addition, ventilation requirements may be dictated by diesel odor considerations. Sufficient data from locomotive engines are not available to make a quantitative estimate at this time.

A "flow-through" catalyst in the exhaust system may be sufficient to address odor issues. Ventilation requirements could be reduced by parking the locomotive in the passenger station with the exhaust directly under a fume uptake hood. In addition, advanced diesel engine emissions control technology is available to reduce NO_x emissions levels to about 8.0 g/hp-hr, a 33 percent reduction. The cost of this technology is $8,400 per locomotive. Some development and proof of concept may be required. The cost of such development is estimated to be $2 million (without certification and durability testing). Operating costs should be the same as the baseline costs.

Liquefied natural gas-fueled locomotive engines can be used to reduce emissions. Currently available retrofit kits from Energy Conversions, Inc reduce NO_x emissions to about 3.6 g/hp-hr, a 70 percent reduction. The conversion cost including engine, fuel tanks and fuel system are about $280,000 per locomotive. Annual inspection and maintenance costs are estimated to be $55,000 per locomotive. Fuel costs are expected to be slightly lower than baseline.

Locomotives may be refueled directly from tanker trucks obviating the need for a storage tank. It is estimated that two tanker truck loads (20,000 to 24,000 gallons of LNG) per day would be required. Alternatively, a fuel storage tank could be built in order to be isolated from uncertainties of fuel deliveries. The cost of a 50,000 gallon storage tank is estimated to be $300,000. Installation costs are highly dependent on local regulations. Annual maintenance costs on the storage tank are estimated to be $75,000. A training program may be needed for CalTrain personnel to handle LNG at -200 degrees F.

A comprehensive fire/safety study is needed to consider the use of LNG in an underground, enclosed situation. Leaking natural gas can accumulate in "pockets" in the tunnel or the passenger station ceiling. Natural gas detection equipment and other safety procedures need to be developed.

More advanced technology to reduce NO_x levels to about 2 to 2.5 g/hp-hr (an 80 percent reduction) is currently under development and may be available in two to three years. Retrofitting ECI technology to this more advanced version should be relatively easy.

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